Chapter 5
Aggregate Elements

5.1 Introduction

The aggregate modeling elements, along with the AeroDyn subroutines, are the true "guts" of ADAMS/WT. It is the aggregate elements which give ADAMS/WT the potential to greatly speed up the overall process of creating a turbine model, and to increase the reliability and credibility of that model. Each aggregate element is defined in ADAMS/WT using industry standard terminology, then automatically constructed from lower-level elements, including both the new low-level ADAMS/WT elements and the standard ADAMS element library. The aggregate elements are:

- Flexible support tower
- Nacelle
- Power train
- Rotor hub (2-, 3-, 4- and 5-bladed, rigid and flexible)
- Rotor blade (rigid/hinged and flexible)

All the aggregate element share some common basic characteristics. First, the automation of their construction, modification, relocation and deletion is based on a standardized naming scheme. For example, all the PARTs and FIELDs in blade number 1 have names that begin with "*bl1_*". It is this consistent naming scheme which allows the ADAMS/WT macros to keep track of the model building process. Except as discussed below for aerodynamics, WT uses the ADAMS/View names, not the ADAMS IDs, to organize the model. After the fundamental model is completed, however, the user may rename it in ADAMS/View, if desired, and work with it freely outside of the WT macro framework.

For the aerodynamic forces, the identifier numbering scheme in the ADAMS/Solver dataset closely corresponds to that suggested by the University of Utah in the AeroDyn User's Guide (see Appendix I)[6]. The <u>required</u> numbering is adhered to exactly wherever it appears in the automatic aggregate element generation.

Remember that ADAMS force elements are always defined between two locations referred to as the "I marker" and the "J marker." In ADAMS/WT, these are consistently arranged for flexible elements so that you progress from J to I as you move up the tower and then out toward the blade tips. Finally, all the aggregate elements have apropos graphics associated with them, so that it is easier to accurately visualize the system configuration, make modifications and understand the responses.

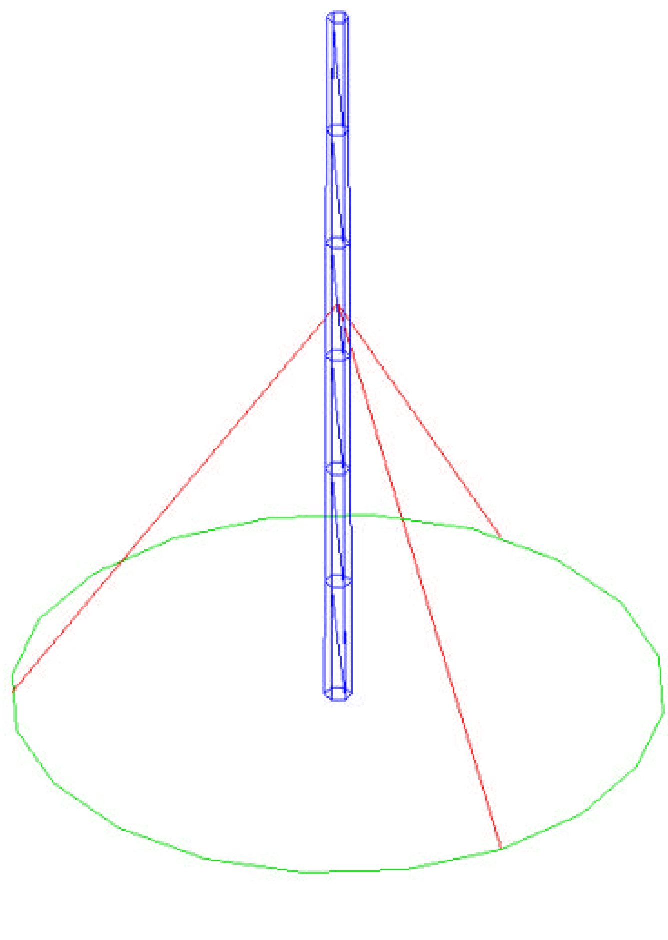
Each of the aggregate elements can be created as a separate entity or as part of a complete wind turbine model. To facilitate this, ADAMS/WT uses the pseudo-realistic method of each object being initially constructed "on the ground", which, in the ADAMS world, means that its initial reference coordinate system is coincident with the origin of the virtual inertial space.

6.Hansen, C. "User's Guide to YawDyn and AeroDyn for ADAMS, Version 11.0, University of Utah, Salt Lake City, UT, January, 1998.

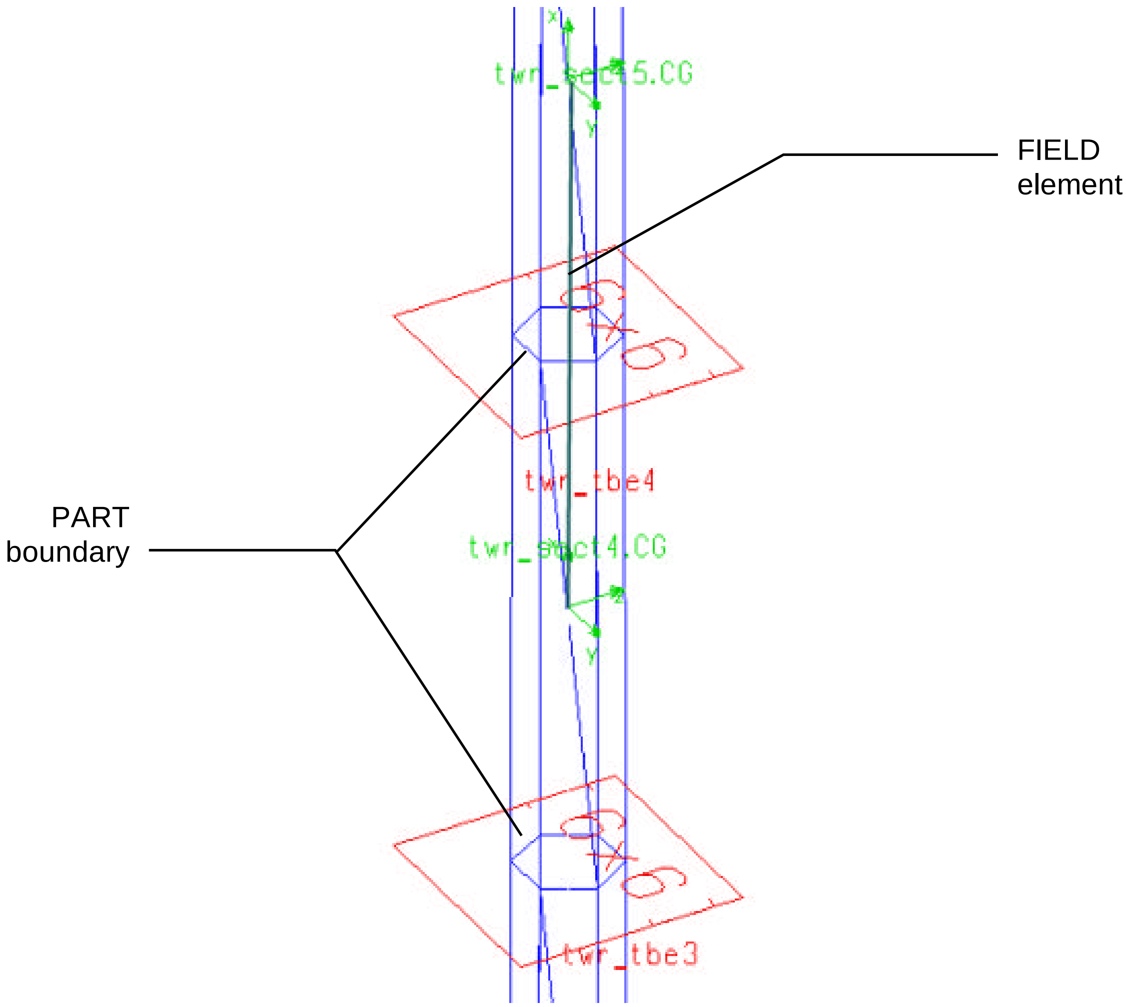
Each aggregate element can then be relocated *en mass* to place it where it belongs in the system model. In most cases, it will be automatically be connected to the other parts of the model with appropriate joints and forces. In a few cases, the user must manually clean up the attachments. When building a turbine model in WT, therefore, it helps to work in the same order, i.e. from the ground up, constructing the virtual turbine much like you would raise a real turbine on site. This is the methodology followed in the example turbine tutorials in Chapters 7 through 10.

5.2 Tower

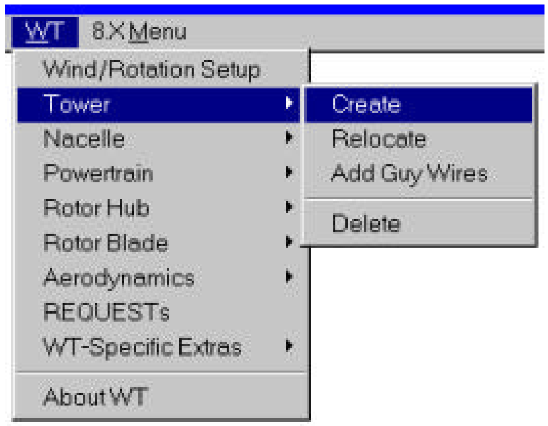
In ADAMS/WT, the tower aggregate element is modeled as a straight, tapered flexible beam using the tapered beam and tapered part low-level elements described in Chapter 4. The tower is actually a somewhat simpler, untwisted version of flexible rotor blade aggregate element (see 5.6 below). Optionally, you may add sets of guy wires to the tower after it has been created.



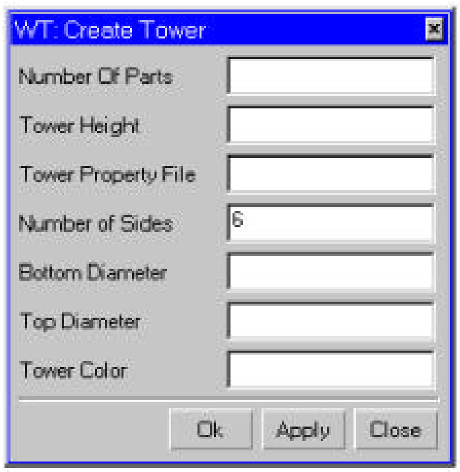
Given the number of parts, N, and the tower height, ADAMS/WT will automatically generate a series of N equal-length tapered parts and tapered beams, attached at one end to the *foundation* MARKER on the *ground* PART and having a *yaw_bottom* MARKER at the other end to serve as the bottom of the yaw bearing. A short section of a completed tower is shown below. While the ADAMS/View icons are a bit difficult to distinguish in the black and white figure, you should note that the tapered beam FIELD elements run between the PART center-of-gravity MARKERs.



The data entry panel for the tower is accessed through the main WT menu:



The CREATE panel for the tower is shown below:



Number of Parts

The number of tapered part PARTs and tapered beam FIELDs which will be used in the tower. The PARTs will all be of equal length. The bottom-most FIELD will be half-length from the ground to the first PART's center-of-gravity; other FIELDs will be equal length.

Tower Height

The height of the tower, m.

Tower Properties File

The actual inertial and stiffness properties for the tower must be in this external file. This file lists, as a function of height, the mass/unit length, section mass moments of inertia, section CG offsets from the centerline, torsional stiffness, lateral stiffnesses and extensional stiffness. ADAMS/WT interpolates and smoothes this data using the external program *wttower.exe* to get the end point values which are passed in to the nested tapered beam and tapered part element macros. A detailed description of the file format and contents is given in Appendix F. (see also 5.6 .1 below - Blade Properties)

Number of Sides

The number of sides to use in the frustum GRAPHICs which are attached to the tower PARTs. For a circular tower, 6 or 8 sides is usually enough for a believable depiction. For a truss tower, enter the actual number of sides. If you do not want tower graphics, enter 0.

Bottom Diameter

The equivalent diameter of the tower at the bottom, m. Used only for graphics.

Top Diameter

The equivalent diameter of the tower at the top, m. Used only for graphics.

Tower Color

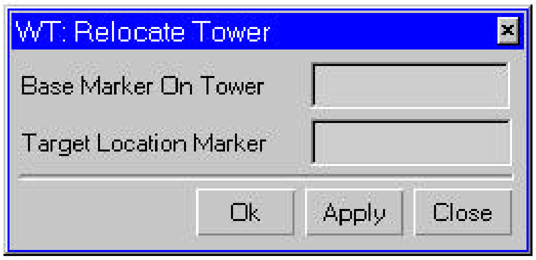
The ADAMS/View color to use for the graphics. Right-click in the field to get a list.

When all the data are entered and the user selects OK, ADAMS/WT will begin the process of creating the entire tower structure, running the *wttower.exe* utility program, creating a set of intermediate temporary files which are automatically read back into View, then finally building the tower itself. This can take up to several minutes, depending on how many sections are in the tower and the speed of your platform.

Tower PARTs are named *twr_sect#* and are numbered from the ground up, starting from 1. The local x-axes of the tower parts and their *CG* MARKERs point up the tower centerline. Tower FIELDs are named *twr_tbe#* and are also numbered from the ground up, starting from 0. The FIELDs run between the part centers-of-gravity, under the assumption that the tower's elastic axis is straight and untwisted.

There is no MODIFY panel for the tower. ADAMS/WT can build a new tower very quickly, so to change the tower, you should delete it entirely and create a completely new tower as above. This is done with the DELETE panel, which is self-explanatory. Note that deleting the tower will also delete any sets of guy wires in the model.

To move the tower, use the RELOCATE panel:



Base Marker on Tower

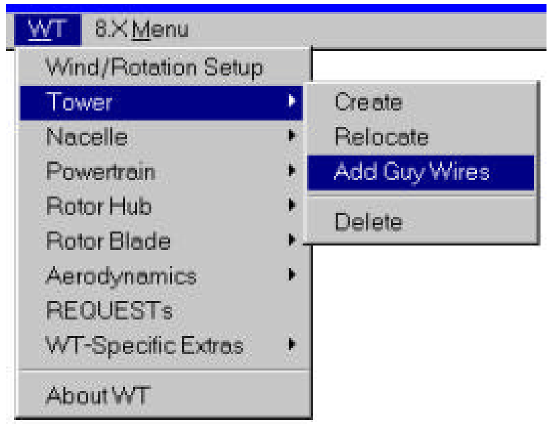
The ADAMS/View name of MARKER on the tower for which you want to specify a new position. Unlike the normal MOVE panel in ADAMS/View, in this case the entire tower structure will move "in formation" with the base marker. After the relocation, the base marker will overlay the target marker exactly. The rest of the tower will maintain relative position and orientation with respect to the base marker. This defaults to the *twr_base* marker.

Target Location Marker

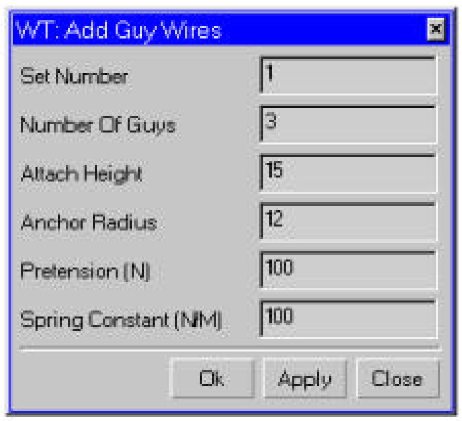
The ADAMS/View name of any MARKER on any other PART in the model. After the relocation, the base marker on the tower will have the exact same position and orientation as the target marker. WT will automatically reconnect the lowest FIELD element to the new "foundation."

5.2.1 Guy Wires

It is possible to attach multiple constellations of guy wires to a tower at different heights above the ground and with different radial spreads. Each set can have a different number of wires, but all wires in the set must have the same pretension and stiffness. The guy wires will be distributed evenly around the base of the tower, with one always being on the global x axis. To add guy wires to a tower, select ADD GUY WIRES from the TOWER sub-menu:



This will bring up the following panel:



Set_number

An integer identifying this particular set of guy wires. Sets should be numbered consecutively, starting with 1.

Number_of_guys

The integer number of wires in this set, not less than three.

Attach_Height

The height of the point at which the guys will be attached to the tower, meters. This is measured from the LPRF of the *twr_sect1* PART. Note that all the guys in one constellation are attached to a single MARKER at the centerline of the tower.

Anchor_Radius

The distance from the centerline of the tower to the circle containing the guy wire anchor points, meters.

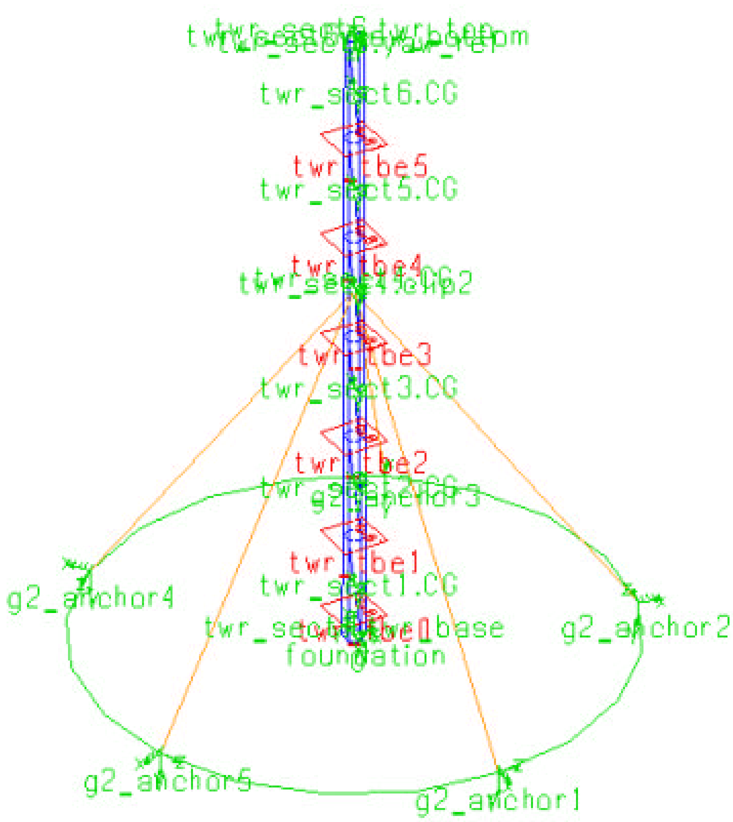
Pretension

The nominal tension in the guy wires <u>as installed</u>, newtons.

Spring_Constant

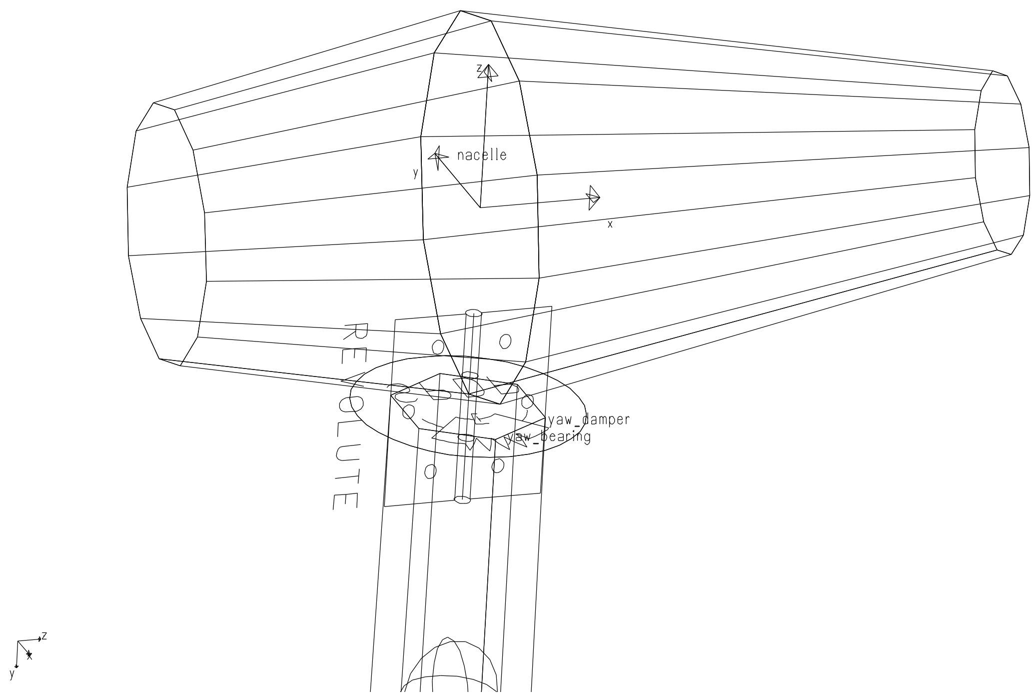
The effective stiffness of the guy wires <u>as installed</u>, newtons/meter. Note that this is <u>not</u> the specification stiffness of the wire itself, which would be given in N/m/m.

After the panel is executed (using OK or APPLY), ADAMS/WT will automatically create a set of SFORCE elements called *guywire--*, between MARKERs at the guy wire anchor points and the attachment MARKER on the tower's centerline. The guy wire SFORCEs act like stretched springs, except that they provide <u>only</u> tension. If the tower deflection is so great as to completely relieve the pretension in one wire, the force in that wire goes to zero. When active, the guy wires have a damping coefficient equal to 1% of the spring constant. A tower with a 5-wire set of guys is shown below, complete with most of the ADAMS/View icons:

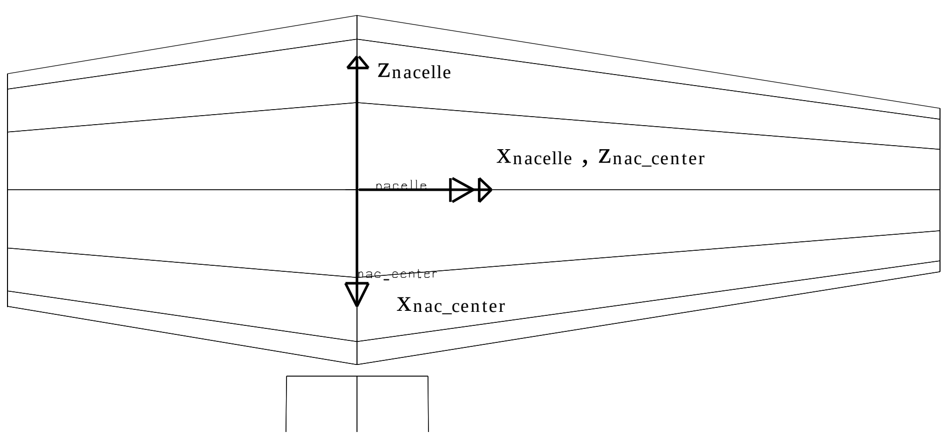


5.3 Nacelle

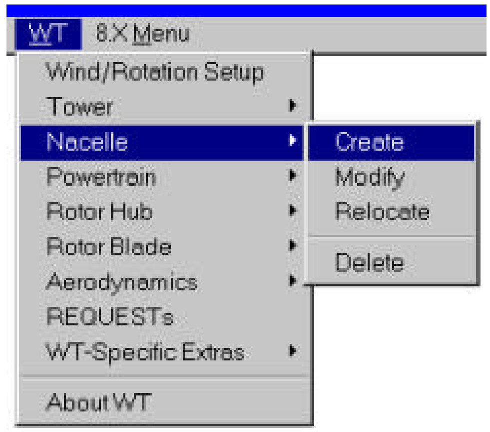
The nacelle is the simplest of the aggregate elements in ADAMS/WT. It consists of only a single ADAMS PART, two frustum GRAPHICs connected base-to-base to represent the shell, a revolute (piano hinge) JOINT simulating the yaw bearing and, optionally, a yaw spring-damper.



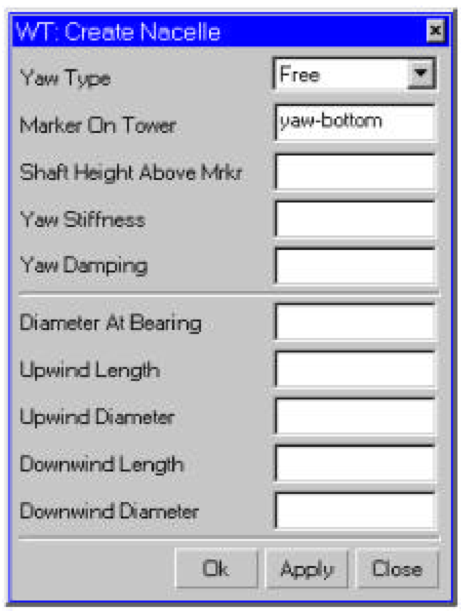
Note that in cases where the axis of the entire power train needs to be pitched, it is recommended that the user tilt (MOVE) the nacelle appropriately, after creating it, but before creating the power train. This is because, by default, the power train is defined relative to the *nac_center* marker, which is located at the *nacelle* part axes, but has its z-axis pointing down the shaft direction.



The data entry panel for the nacelle is accessed through the main WT menu:



The CREATE panel for the nacelle is shown below:



Yaw Type

ADAMS/WT allows for three type of attachments from the nacelle to the tower: fixed yaw, free yaw (with damper) and yaw drive. (The yaw drive option for upwind rotors is not implemented in release 2.0).

Shaft Height Above Marker

The distance along the tower axis from the *twr_top* MARKER to the centerline of the nacelle. The *nac_center* MARKER will be located at this point and is used as the reference axis for both the nacelle graphics and later for the power train (section 5.4).

Yaw Stiffness

The rotational stiffness of the *yaw_damper* SRPINGDAMPER on the *yaw_bearing* JOINT, N-m/deg. If both stiffness and damping are zero, ADAMS/WT will not create the damper element.

Yaw Damping

The rotational damping of the *yaw_damper* SPRINGDAMPER on the *yaw_bearing* JOINT, N-m-sec/deg. If both stiffness and damping are zero, ADAMS/WT will not create the damper element.

Diameter at Bearing

The diameter of the nacelle frustum GRAPHICs at the *nac_center* MARKER, m. Note that all diameters specified here are for graphics only. **The user must manually add mass properties to the nacelle using PART MODIFY from the 8.X menu or using the MASS PROPERTIES button on the NACELLE MODIFY panel.**

Upwind Diameter

The nacelle diameter at the upwind end, m.

Upwind Length

The length of the nacelle in the upwind direction, m.

Downwind Diameter

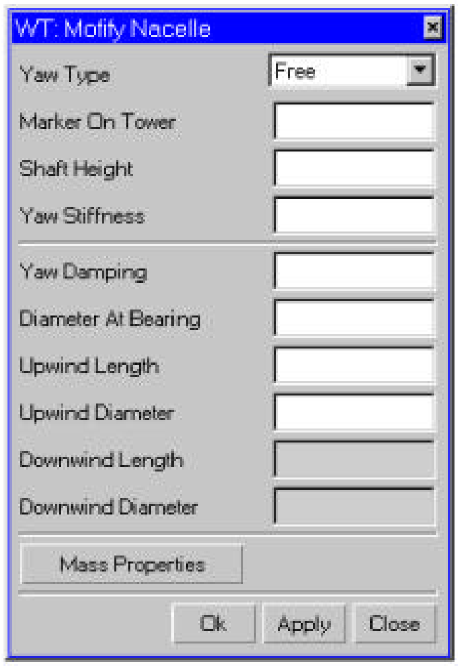
The nacelle diameter at the downwind end, m.

Downwind Length

The length of the nacelle in the downwind direction, m.

When all the data are entered and the user selects OK, ADAMS/WT will automatically create the nacelle aggregate element. If there is already a tower in your model with a *yaw_bottom* MARKER in it, WT will also create the *yaw_bearing* JOINT and *yaw_damper* SPRINGDAMPER connecting it to the nacelle.

The MODIFY panel for the nacelle is very similar to the CREATE panel. Note however that the NACELLE MODIFY panel will not properly modify nacelle position or graphics if you have subsequently added parts of the power train to the model. It will only work properly immediately after the nacelle is created. You can, however, modify the nacelle's mass properties at any time.



MASS PROPERTIES

Selecting this button brings up the standard PART mass properties modification panel. If you change only the *nacelle* mass properties, you can CLOSE out of the NACELLE MODIFY panel after completing the PART MODIFY panel.

The MASS PROPERTIES button highlights an important characteristic of ADAMS: that a PART's graphics can be totally unrelated to its inertia properties. Because of this, a separate operation is needed to add mass and inertia to the nacelle. **The user should <u>finish creating</u> the nacelle before coming back to it for a separate MODIFY operation to add inertia properties.** Because the power train's *stator* PART will be fixed to the nacelle, the user can split the total non-rotating inertia above the yaw bearing between the nacelle and the stator as desired.

The DELETE panel for the nacelle is self-explanatory.

The RELOCATE panel is shown below:

Base Marker on Nacelle

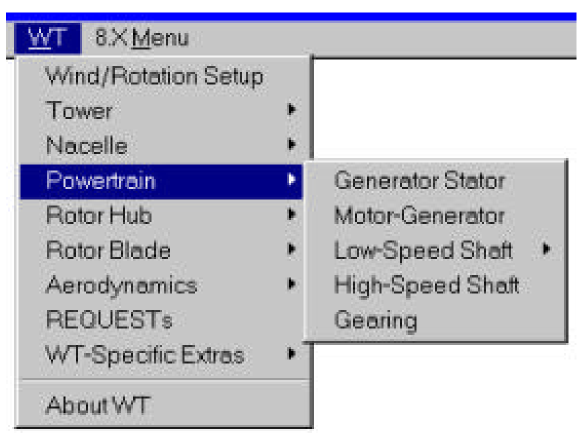
The ADAMS/View name of MARKER on the nacelle for which you want to specify a new position. Unlike the normal MOVE panel in ADAMS/View, in this case the entire nacelle PART will move "in formation" with the base marker. After the relocation, the base marker will overlay the target marker exactly.

Target Location Marker

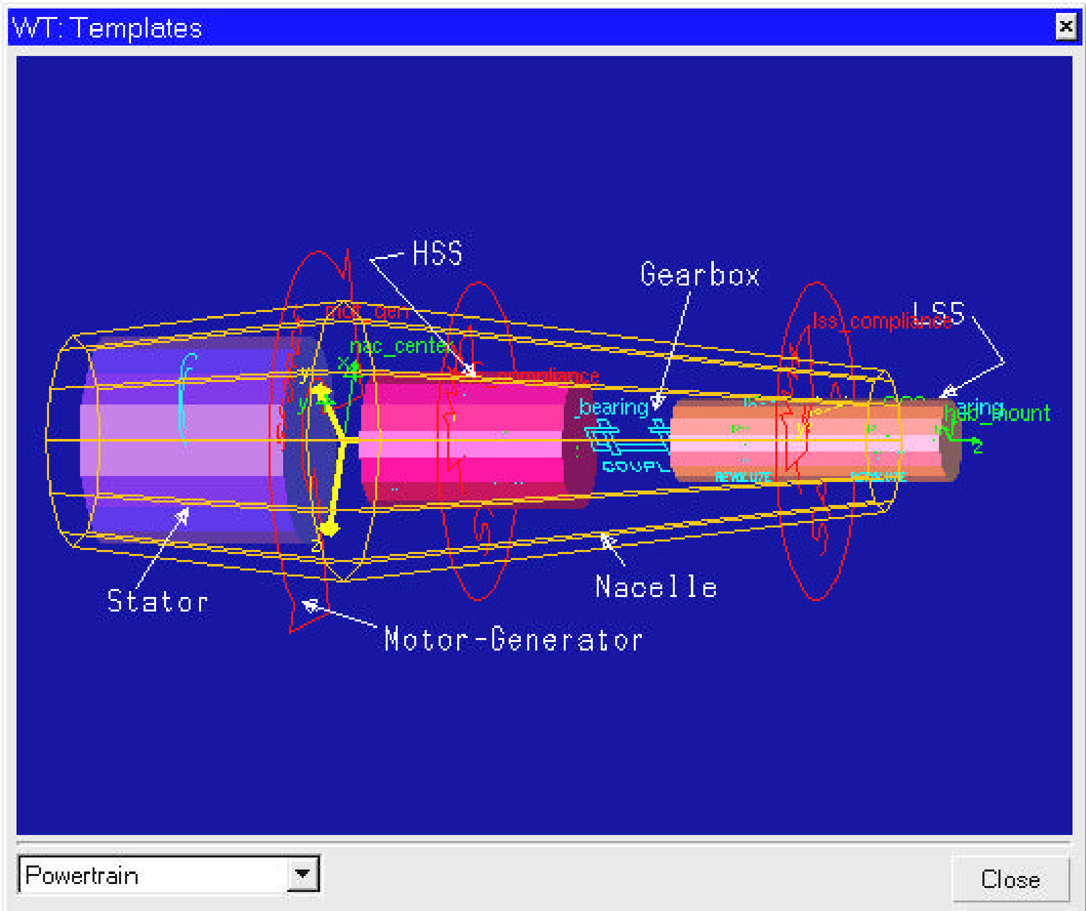
The ADAMS/View name of any MARKER on any <u>other</u> PART in the model. After the relocation, the base marker on the nacelle will have the exact same position and orientation as the target marker.

5.4 Power Train

The power train aggregate element is probably the most complex in the ADAMS/WT system. It can contain a stator PART, a motor-generator SFORCE, a two-PART high-speed shaft with an internal torsional compliance SPRINGDAMPER and bearing JOINTs, and a gearbox COUPLER constraint. The power train also includes a low-speed shaft, either a two-PART shaft with a torsional compliance SPRINGDAMPER and bearing JOINTs like the high speed shaft, or a 3-PART fully-flexible shaft with two internal BEAM elements and a single JOINT. The sub-menu for the power train is accessed through the main WT menu:



Because of its complexity, ADAMS/WT has a graphical template of the power train which is displayed when any POWER TRAIN element is selected:

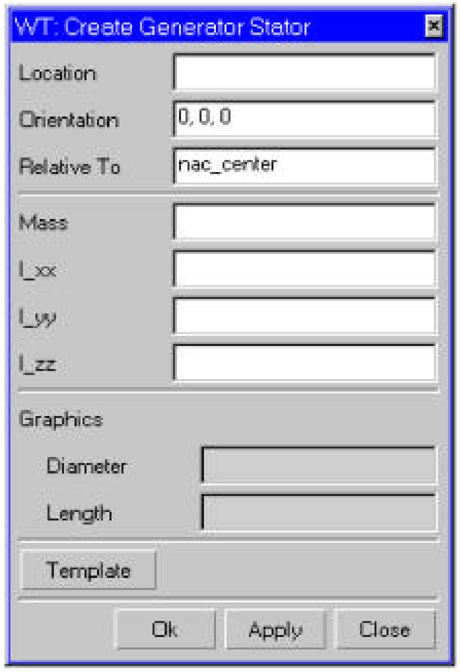


Although this template shows a downwind configuration, WT allows for easy creation of downwind and upwind configurations. By choosing specific portions of the power train to include in the model, and locating them carefully, the user can usually tailor it to the turbine of interest. Unfortunately, there is a very wide range of existing power train configurations, for some of which the power train aggregate element may not be suitable. In those cases, the user will need to do more of the lower-level model definition work on his/her own.

5.4.1 Generator Stator

The generator body (or *stator*) PART in ADAMS/WT is used to model all the non-rotating inertia in the power train. ADAMS/WT includes a separate element for the generator body for convenience in making subsequent changes to the model. Because the stator PART will be rigidly connected to the nacelle PART with a fixed-type JOINT, they could be modeled together as a single entity. The user is free to distribute non-rotating mass and inertia between the nacelle and generator body as desired, so long as the composite mass properties are correct.

Selecting the GENERATOR STATOR menu item brings up the panel shown below:



Location

The x,y,z positions of the center-of-gravity of the generator body in the coordinate system specified by the Relative_to parameter, m.

Orientation

Three Euler angles describing the orientation of the principal axes of the generator body, starting from the coordinate axes specified by the Relative_to parameter, degrees.

Relative_to

A valid ADAMS/View coordinate system specifier, usually the *nac_center* MARKER in the nacelle.

Mass

The mass of the generator body, kg.

I_xx

The principal (second) mass moment of inertia of the generator body around the x-axis of the CG as specified above, kg-m^2.

I_yy

The principal (second) mass moment of inertia of the generator body around the y-axis of the CG as specified above, kg-m^2.

I_zz

The principal (second) mass moment of inertia of the generator body around the z-axis of the CG as specified above, kg-m^2.

Graphics Diameter

The diameter of generator body, depicted in ADAMS/View as a solid cylinder centered on the CG location given above, m.

Graphics Length

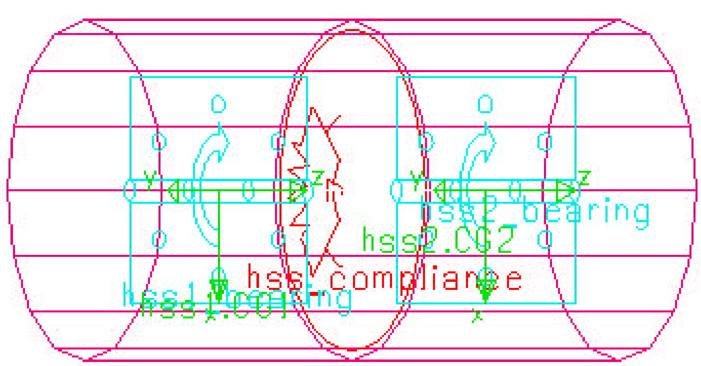
The length of generator body, depicted in ADAMS/View as a solid cylinder centered on the CG location given above, m. The cylinder's length is along the CG MARKER's z-axis.

Template

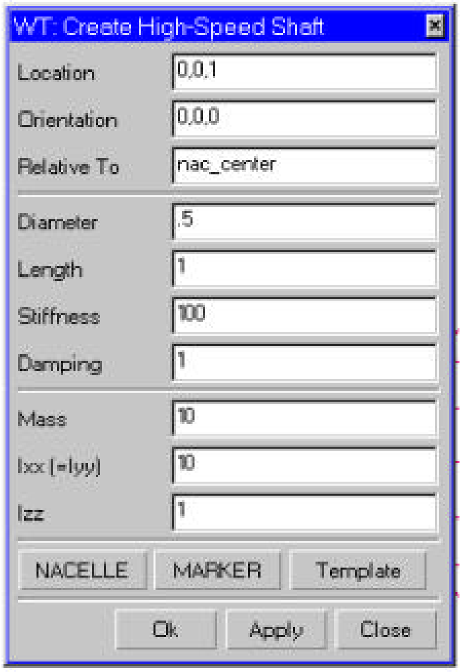
Selecting this button will display the graphical template of the powertrain, if not currently displayed.

5.4.2 High-Speed Shaft

The high-speed shaft element in ADAMS/WT consists of two PARTs, *hss1* and *hss2*, constrained to the nacelle by revolute JOINTs, *hss1_bearing* and *hss2_bearing*, and connected to each other by a torsional SPRINGDAMPER called *hss_compliance*. It is designed to model the section of the drive train that rotates at motor-generator output speed.



Selecting the HIGH-SPEED SHAFT button on the power train sub-menu will bring up this panel:



Location

The x,y,z positions of the composite center-of-gravity of the high-speed shaft in the coordinate system specified by the Relative_to parameter, meters. ADAMS/WT will automatically locate the two halves of the high-speed shaft correctly from this location.

Orientation

Three Euler angles describing the orientation of the principal axes of the high-speed shaft, starting from the coordinate axes specified by the Relative_to parameter, degrees. The shaft should be oriented so that the z-axis is the axis of rotation.

Relative_to

A valid ADAMS/View coordinate system specifier, usually the *nac_center* MARKER in the nacelle.

Diameter

The diameter of the high-speed shaft graphics, depicted in ADAMS/View as two solid cylinders centered on the CG Location given above, m. ADAMS/WT does not compute inertia properties using this value.

Length

The actual length of high-speed shaft, m. This length is used to determine correct apportionment of the high-speed shaft inertia to the two PARTs. The shaft is depicted in ADAMS/View as two solid cylinders centered on the CG Location.

Stiffness

The effective torsional stiffness of the high-speed shaft, N-m/deg. Typically, this value is used with the inertial data to approximate the shaft's first torsional mode frequency. If the user enters zero values for both stiffness and damping, ADAMS/WT will assume a rigid shaft and "weld" the two halves together with a fixed-type JOINT.

Damping

The effective torsional damping of the high-speed shaft, N-m-sec/rad. If the user enters zero values for both stiffness and damping, ADAMS/WT will assume a rigid shaft and "weld" the two halves together with a fixed-type JOINT.

Mass

The mass of the high-speed shaft, kg. ADAMS/WT will automatically split the mass in half and apply it to each of the shaft PARTs.

Ixx (=Iyy)

The principal (second) mass moment of inertia of the high-speed shaft around the x-axis (cross axis) of the CG as specified above, kg-m^2. ADAMS/WT will automatically recompute the moments of inertia for the separate high-speed shaft half PARTs based on the given Length.

Izz

The principal (second) mass moment of inertia of the high-speed shaft around the z-axis (long axis) of the CG as specified above, kg-m^2. ADAMS/WT will automatically split the inertia in half and apply it to each of the PARTs.

NACELLE

Selecting this button will bring up the nacelle creation panel.

MARKER

Selecting this button will bring up the marker creation panel.

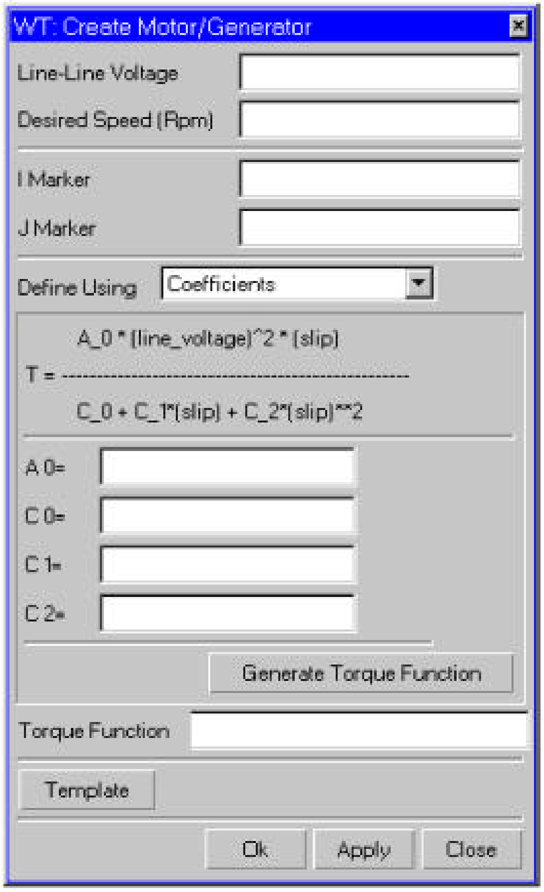
Template

Selecting this button will bring up the powertrain graphic template.

When all the data are entered and the user selects OK, ADAMS/WT will automatically create the entire high-speed shaft aggregate element. Note that if the shaft is rigid, one of the revolute JOINTs created by ADAMS/WT will be redundant and should be removed.

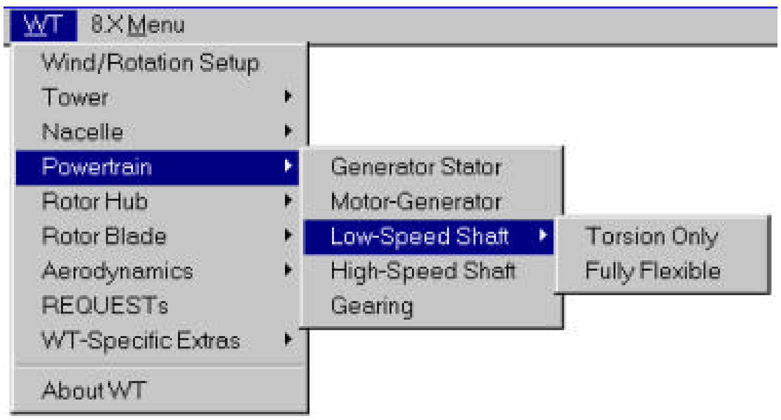
5.4.3 Motor-Generator

Selecting the MOTOR_GENERATOR button on the power train sub-menu will display the motor-generator creation panel (for a detailed description of the motor-generator, see section 4.3). The *mot_gen* SFORCE element will normally be created between the *stator* and the *hss1* PARTs.



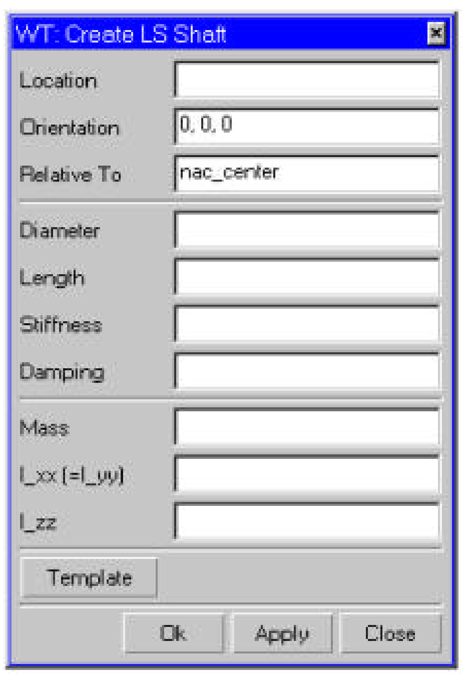
5.4.4 Low-Speed Shafts

As mentioned above, there are two options available for the low-speed shaft, accessed by selecting the LOW-SPEED SHAFT button on the power train sub-menu. You may choose either a fully flexible, beam-like shaft or a shaft with torsional flexibility only. The low-speed shaft is designed to model that part of the drive train that rotates at the rotor speed.



<u>Torsional Flexibility Only</u>

The first option is for torsional flexibility only, exactly like the high-speed shaft. For this option, the low-speed shaft element in ADAMS/WT consists of two PARTs, *lss1* and *lss2*, constrained to the nacelle by revolute JOINTs, *lss1_bearing* and *lss2_bearing*, and connected to each other by a torsional SPRINGDAMPER called *lss_compliance*. Selecting the TORSION ONLY button on the LSS sub-menu will bring up this panel:



Location

The x,y,z positions of the composite center-of-gravity of the low-speed shaft in the coordinate system specified by the Relative_to parameter, m. ADAMS/WT will automatically locate the two halves of the low-speed shaft correctly from this location.

Orientation

Three Euler angles describing the orientation of the principal axes of the low-speed shaft, starting from the coordinate axes specified by the Relative_to parameter, degrees. The shaft should be oriented so that the z-axis is the axis of rotation.

Relative_to

A valid ADAMS/View coordinate system specifier, usually the *nac_center* MARKER on the nacelle.

Diameter

The diameter of the low-speed shaft graphics, depicted in ADAMS/View as two solid cylinders centered on the CG Location given above, m. ADAMS/WT does <u>not</u> compute inertia properties using this value.

Length

The actual length of low-speed shaft, m. This length is used to determine correct apportionment of the low-speed shaft inertia to the two PARTs. The shaft is depicted in ADAMS/View as two solid cylinders centered on the CG Location given above.

Stiffness

The effective torsional stiffness of the low-speed shaft, N-m/deg. Typically, this value is used with the inertial data to approximate the shaft's first torsional mode frequency. If the user enters zero values for <u>both</u> stiffness and damping, ADAMS/WT will assume a rigid shaft and "weld" the two halves together with a fixed-type JOINT called *lss*_weld, and automatically remove the *lss2_bearing* revolute JOINT.

Damping

The effective torsional damping of the low-speed shaft, N-m-sec/rad. If the user enters zero values for <u>both</u> stiffness and damping, ADAMS/WT will assume a rigid shaft and "weld" the two halves together with a fixed-type JOINT called *lss*_weld, and automatically remove the *lss2_bearing* revolute JOINT.

Mass

The mass of the low-speed shaft, kg. ADAMS/WT will automatically split the mass in half and apply it to each of the PARTs.

Ixx (=Iyy)

The principal (second) mass moment of inertia of the low-speed shaft around the x-axis (cross axis) of the CG as specified above, kg-m^2. ADAMS/WT will automatically recompute the moments of inertia for the separate low-speed shaft PARTs based on the given Length.

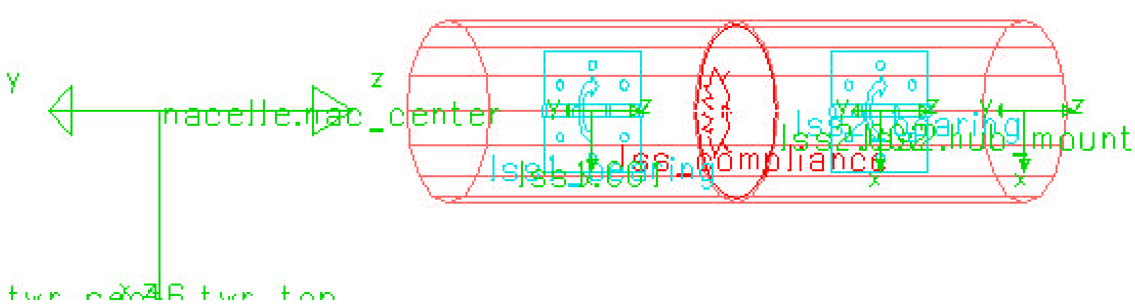
Izz

The principal (second) mass moment of inertia of the low-speed shaft around the z-axis (long axis) of the CG as specified above, kg-m^2. ADAMS/WT will automatically split the inertia in half and apply it to each of the PARTs.

Template

Selecting this button will bring up the powertrain graphic template.

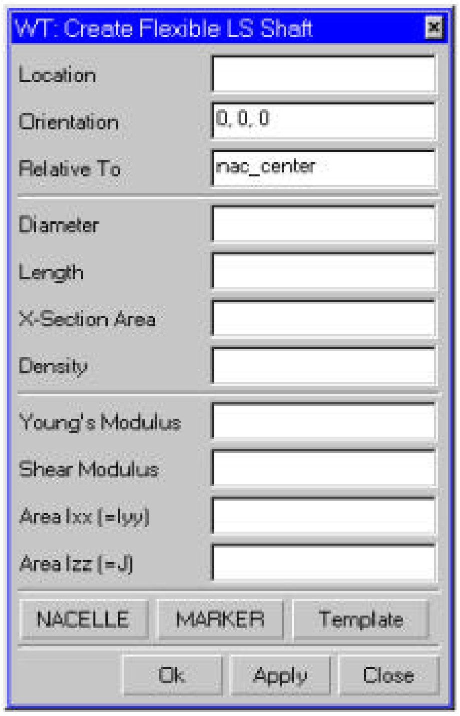
When all the data are entered and the user selects OK, ADAMS/WT will automatically create an entire low-speed shaft aggregate element, adding a *hub_mount* MARKER at the far (down-line) end of the shaft. This will be downwind for downwind rotors and upwind for upwind rotors.



Note that if the shaft is modeled as rigid (no compliance), the *lss2_bearing* revolute JOINT would be redundant. The location of the *lss1_bearing* can also be manually changed by the user to more closely match actual bearing locations (use JOINT MODIFY or the MOVE panel from the 8.X Menu)**.**

Fully Flexible

The second option low-speed shaft option is for a fully flexible shaft. For this option, the low-speed shaft element in ADAMS/WT consists of three PARTs, *lss1*, *lss2*, and *lss3*, constrained to the nacelle by a single revolute JOINT, *lss1_bearing*, at the inboard end. (Actually, there is also a dummy fourth PART in the low-speed shaft called *lss0*.) The PARTs are connected to each other by BEAMs called *lss01*, *lss12* and *lss23*. Selecting the FULLY FLEXIBLE button on the LOW-SPEED SHAFT sub-menu will bring up this panel:



Location

The x,y,z positions of the composite center-of-gravity of the low-speed shaft in the coordinate system specified by the Relative_to parameter, meters. ADAMS/WT will automatically locate the three parts of the low-speed shaft correctly from this location.

Orientation

Three Euler angles describing the orientation of the principal axes of the low-speed shaft, starting from the coordinate axes specified by the Relative_to parameter, degrees. The shaft should be oriented so that the z-axis is the axis of rotation.

Relative_to

A valid ADAMS/View coordinate system specifier, usually the *nac_center* MARKER on the nacelle.

Diameter

The diameter of the low-speed shaft graphics, depicted in ADAMS/View as two solid cylinders centered on the CG Location given above, meters. ADAMS/WT does not compute inertia properties using this value.

Length

The actual length of low-speed shaft, meters. This length is used to determine correct values and apportionment of the low-speed shaft mass properties to the three PARTs. The shaft is depicted in ADAMS/View as three solid cylinders in line, centered on the CG Location given above.

X-Section Area

The actual cross-section area of the shaft, meters^2. ADAMS/WT uses this value, along with density, to compute shaft inertia properties and along with the modulus to compute extensional stiffness.

Density

The actual density of the shaft, kg/m^3. ADAMS/WT assumes that the shaft is uniform along its entire length.

Young's Modulus

The modulus of elasticity of the shaft material, N/m^2. This is assumed to be the same in both tension and compression. Used with the area moments to compute bending stiffnesses.

Shear Modulus

The modulus of rigidity of the shaft material, N/m^2. This is assumed to be the same in both tension and compression. Used with the polar area moments to compute torsional stiffnesses.

Ixx (=Iyy)

The principal (second) area moment of inertia of the low-speed shaft around the x-axis (cross axis) of the CG as specified above, m^4. Used with the Young's modulus to get beam bending stiffnesses and with the density to get mass moments for the shaft PARTs.

Izz (=J)

The polar area moment of inertia of the low-speed shaft around the z-axis (long axis) of the CG as specified above, m^4. ADAMS/WT assumes that the shaft will have a circular cross section. Used with the shear modulus to compute torsional stiffness and with the density to compute mass moments for the shaft PARTs.

NACELLE

Selecting this button will bring up the nacelle creation panel, in case you have forgotten to do this first!

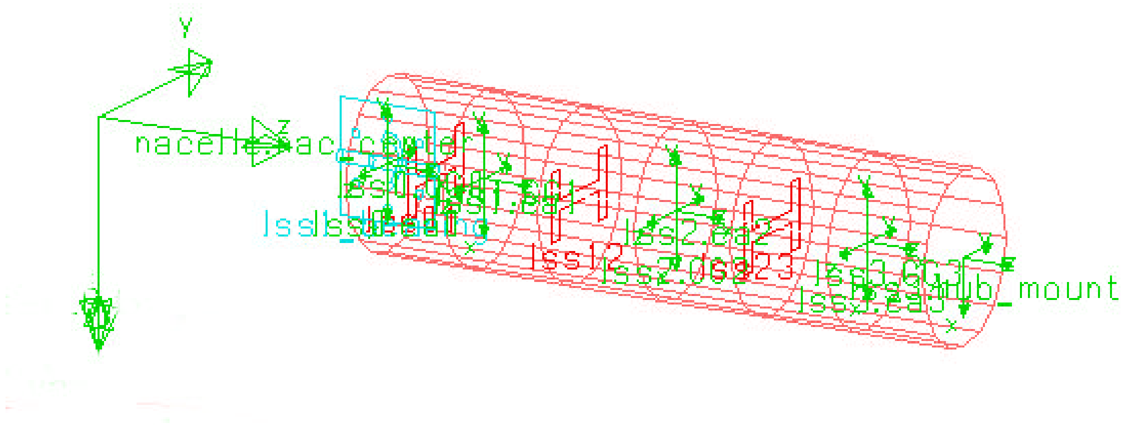
MARKER

Selecting this button will bring up the marker creation panel.

Template

Selecting this button will bring up the powertrain graphic template.

When all the data are entered and the user selects OK or APPLY, ADAMS/WT will automatically create the entire low-speed shaft aggregate element, including the three *lss_* PARTs and BEAMs and adding a *hub_mount* MARKER at the far (down-line) end of the shaft. This will be downwind for downwind rotors and upwind for upwind rotors. A downwind rotor's low-speed shaft should look similar to that shown below:



5.4.5 Gearing

The power train aggregate element allows for the effect a single gearbox in the system, usually between the high-speed and low-speed shafts. The gearing is actually implemented in the model and dataset as an ADAMS COUPLER, a special type of constraint which forces a fixed displacement ratio to be maintained between two separate joints. In the "standard" power train, the gearing would couple the rotational motions of second high-speed shaft PART with the first low-speed shaft PART on their respective bearings.

Note that the gearing element in ADAMS/WT is massless and the user should add the rotary inertia of the gearbox to either the high-speed or the low-speed shaft, being sure to correctly account for the gear ratio. Note also that the COUPLER element produces perfect gearing, that is without any internal slop, backlash, flexibility or friction. In this version of WT, the COUPLER does correctly account for the torque that would normally be transferred to the gearbox housing, as long as both joints in the COUPLER have the same J part (usually the *nacelle)*, and the shafts are parallel.

Selecting GEARING on the power train sub-menu will display the data entry panel for the gearing element:

HSS Joint

The ADAMS/View name of the "up-line" JOINT in the gearing. Usually *hss2_bearing*, but does not strictly have to be on the high-speed shaft.

LSS Joint

The ADAMS/View name of the "down-line" JOINT in the gearing. Usually *lss1_bearing*, but does not strictly have to be on the low-speed shaft.

Gear Ratio

The ratio between the high-speed shaft motion and the low-speed shaft motion. If the gearing drops the shaft speed by a factor of 5, for example, enter a 5 here.

LSS

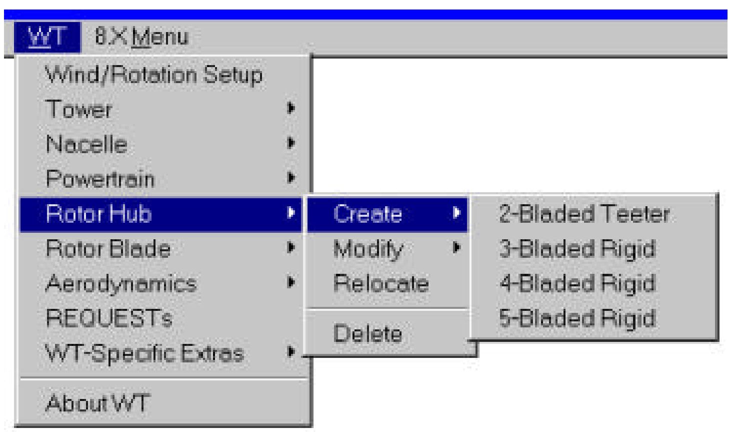
Selecting this button will bring up the low-speed shaft creation panel, in case you have not yet created it. You can not create gearing unless both high-speed and low-speed shafts already exist in your model

HSS

Selecting this button will bring up the high-speed shaft creation panel, in case you have not yet created it. You can not create gearing unless both high-speed and low-speed shafts already exist in your model
.

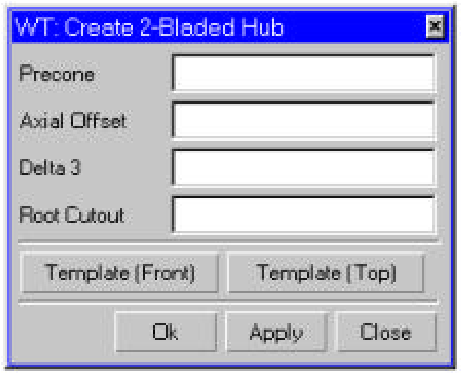
5.5 Rotor Hubs

ADAMS/WT can automatically generate four types of rotor hubs, a two-bladed teetering hub, a three-bladed rigid hub, a four-bladed rigid hub and a five-bladed rigid hub. For all hub types, the hub structure can be considered to be either rigid or flexible *at the blade attachment points*. Between the blade attachment points and the shaft attachment point the hub is considered to be rigid. To ensure that the correct parameters are entered for the hub, each type has an associated graphic template on which the parameter definitions are clearly marked. The hub creation panels are accessed through the WT menus:



5.5.1 2-Bladed Teetering Hub

Selecting the 2-BLADED TEETER button will display this data entry panel:



Precone

The angle between the shaft normal and the blade attachment MARKER x-axis, degrees. Positive precone is out of the wind.

Axial_Offset

The distance along the shaft axis from the *hub_center* MARKER to the blade attachment points, m. This can also be thought of as the distance along the shaft from the teetering pin to the plane of the blade attachments. For typically underslung rotors, this value may be negative, depending on the precone and root cutout values.

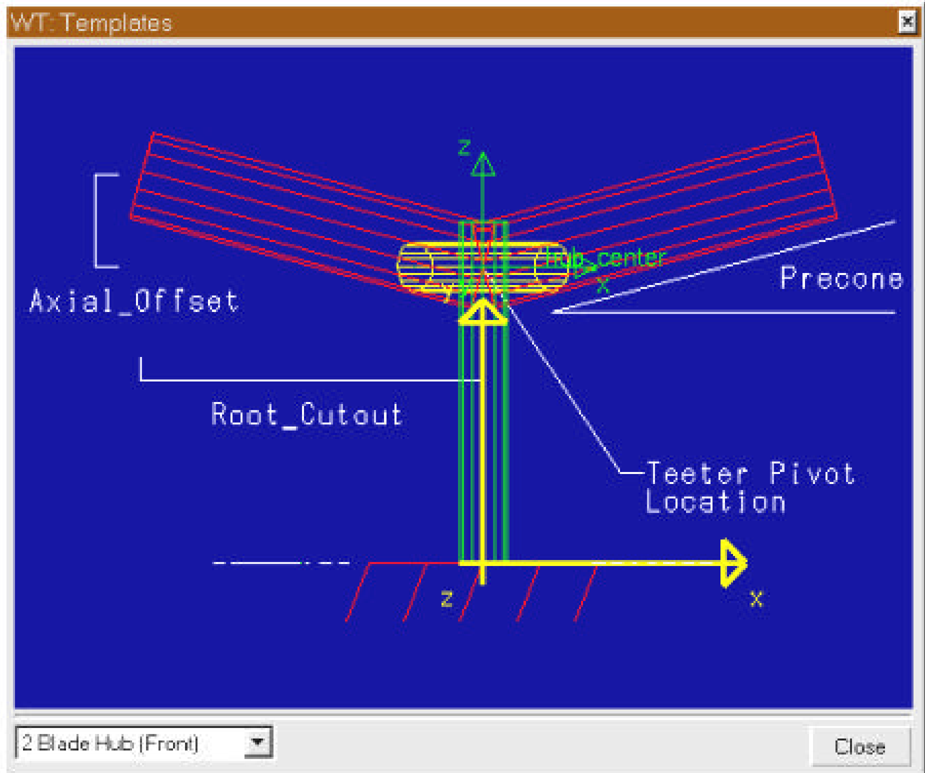
Delta_3

The angle between the teetering axis and the plane defined by the hub center and the two blade attachment points, degrees. The angle is measured positive in the direction opposite the direction of rotation, so that positive δ_3 angle results in a flap-up, pitch-down coupling. ADAMS/WT will place the *teeter* MARKER at the same position along the shaft as the *hub_center*, but with it z-axis aligned δ_3 degrees from the blade plane.

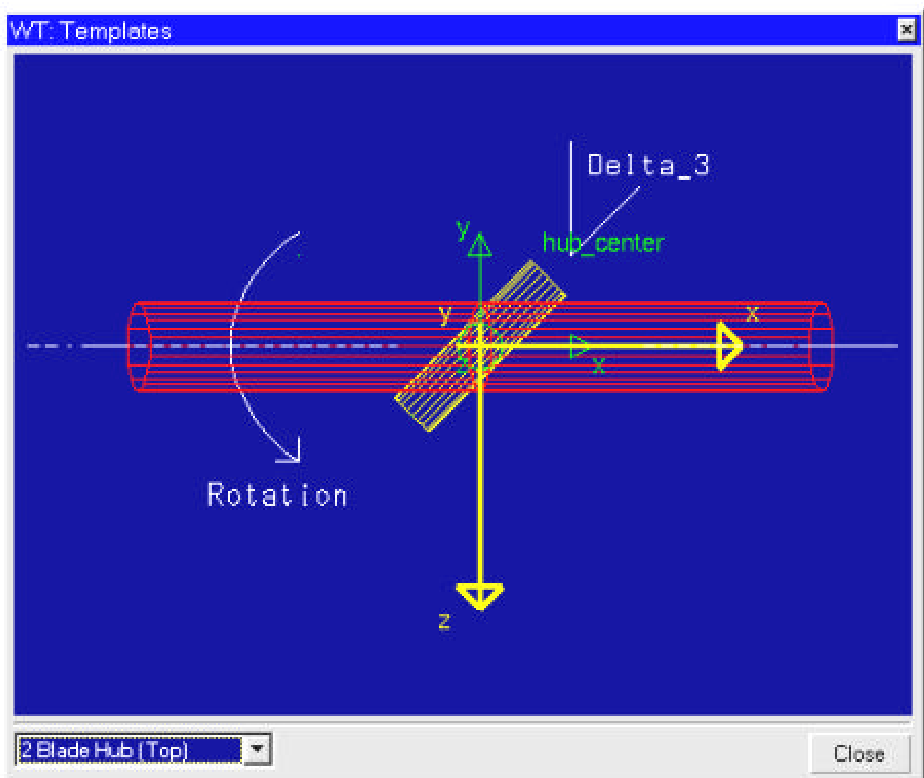
Root_Cutout

The radial distance (along a normal to the shaft, not along the blade axis), from the hub center to the blade attachment circle, m. If the distance along the blade axis from the blade root to the shaft centerline is l_{rc} , and the precone angle is b, then the root_cutout is $l_{rc} \cos b$.

Template (Front)

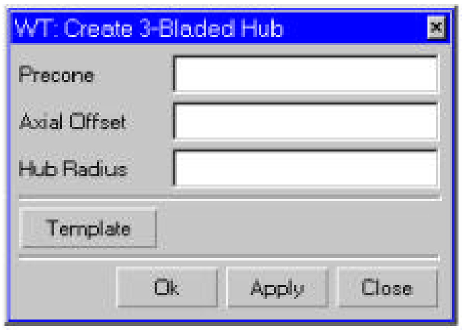


Template (Top)



5.5.2 3-Bladed Rigid Hub

Selecting the 3-BLADED RIGID button will display this data entry panel:



Precone

The angle between the shaft normal and the blade attachment MARKER x-axis, degrees. Positive precone is out of the wind.

Axial_Offset

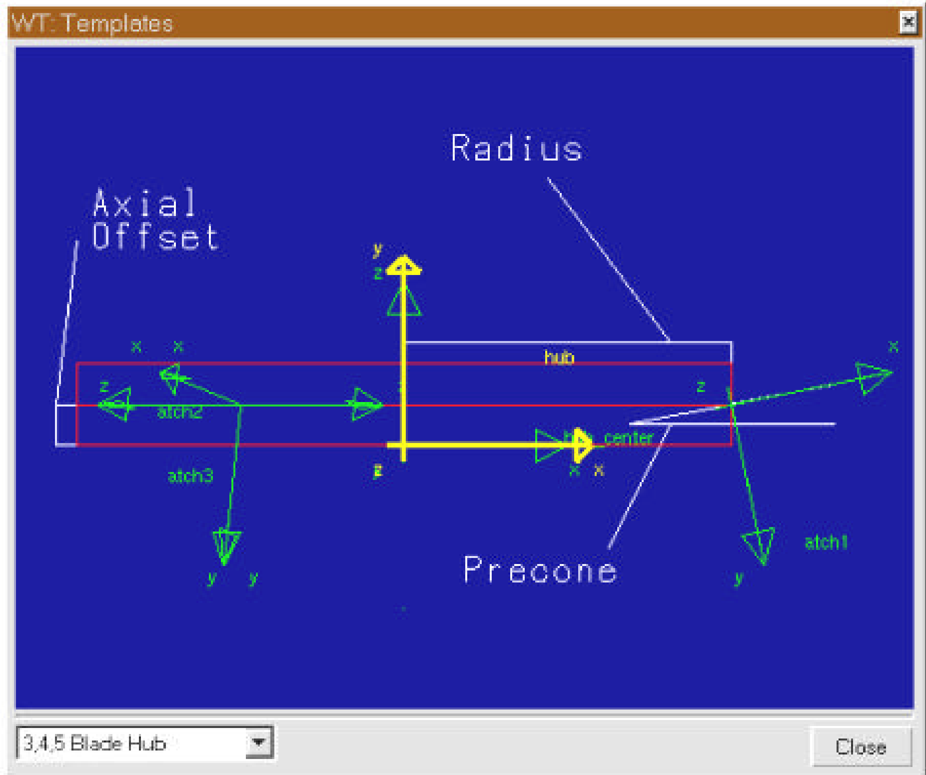
The distance along the shaft axis from the *hub_center* MARKER to the blade attachment points, m. This can also be thought of as the distance along the shaft from the hub-shaft connection to the plane of the blade attachments. For typical rotors, this distance will be positive.

Hub_Radius

The radial distance (along a normal to the shaft, not along the blade axis), from the hub center to the blade attachment circle, m. If the distance along the blade axis from the blade root to the shaft centerline is l_{rc} , and the precone angle is b, then the hub_radius is $l_{rc} \cos b$.

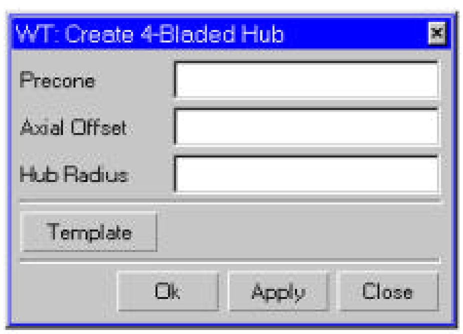
Template

Selecting this button will bring up the generic template for 3-, 4- and 5-bladed rigid hubs.



5.5.3 4-Bladed Rigid Hub

Selecting the 4-BLADED RIGID button will display this data entry panel:



Precone

The angle between the shaft normal and the blade attachment MARKER x-axis, degrees. Positive precone is out of the wind.

Axial_Offset

The distance along the shaft axis from the *hub_center* MARKER to the blade attachment points, m. This can also be thought of as the distance along the shaft from the hub-shaft connection to the plane of the blade attachments. For typical rotors, this distance will be positive.

Hub_Radius

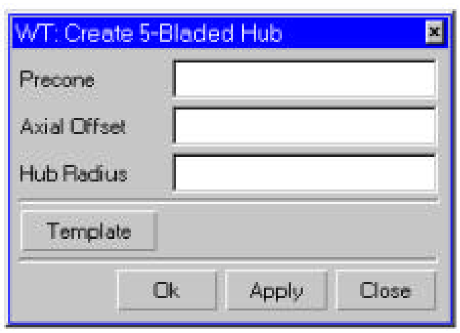
The radial distance (along a normal to the shaft, not along the blade axis), from the hub center to the blade attachment circle, m. If the distance along the blade axis from the blade root to the shaft centerline is l_{rc} , and the precone angle is β, then the hub_radius is $l_{rc} \cos\beta$.

Template

Selecting this button will bring up the generic template for 3-, 4- and 5-bladed rigid hubs.

5.5.4 5-Bladed Rigid Hub

Selecting the 5-BLADED RIGID button will display this data entry panel:



Precone

The angle between the shaft normal and the blade attachment MARKER x-axis, degrees. Positive precone is out of the wind.

Axial_Offset

The distance along the shaft axis from the *hub_center* MARKER to the blade attachment points, m. This can also be thought of as the distance along the shaft from the hub-shaft connection to the plane of the blade attachments. For typical rotors, this distance will be positive.

Hub_Radius

The radial distance (along a normal to the shaft, not along the blade axis), from the hub center to the blade attachment circle, m. If the distance along the blade axis from the blade root to the shaft centerline is l_{rc} , and the precone angle is b, then the hub_radius is $l_{rc} \cos b$.

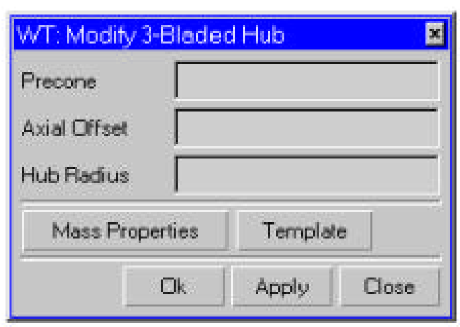
Template

Selecting this button will bring up the generic template for 3-, 4- and 5-bladed rigid hubs.

When any of these panels is executed, ADAMS/WT will create the *hub* PART and place *atch#* MARKERs at each blade attachment point according to the positioning information given. The *atch#* MARKERs will be oriented corresponding to the direction of rotation, pointing outward for clockwise rotation and inward for counter-clockwise rotation. WT will also add some simple graphics to aid in visualizing the hub, although these are <u>not</u> related to hub's mass properties. If you wish, you can replace or change the graphics to look more like your actual hub.

Note also that WT does not automatically include a hub spring or teetering stops for the 2-bladed hub; these must be manually added later by the user.

As was required for the nacelle, **the user must separately add mass properties to the hub through the appropriate HUB MODIFY panel**. (You could also use the PART MODIFY selection from the Command Navigator or 8.X Menu.) For each hub type, the MODIFY panel is very similar to the CREATE panel, with the addition of a MASS PROPERTIES button. For example, here is the 3-bladed HUB MODIFY panel:



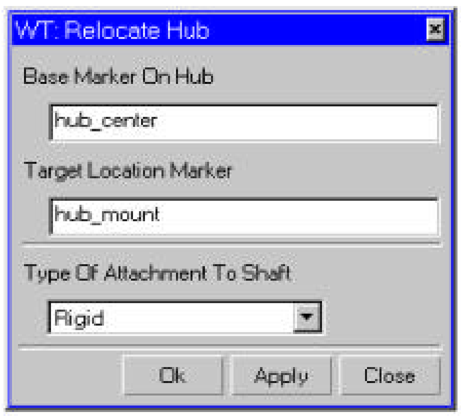
MASS PROPERTIES

Selecting this button brings up the standard PART mass properties modification panel for the *hub*. If you are only adding mass properties to the hub, you can quit out of the HUB MODIFY panel after completing the PART MODIFY panel for the *hub*. This will add the mass properties to the *hub*, but not change anything else.

The MASS PROPERTIES button highlights an important characteristic of ADAMS: that a PART's graphics can be totally unrelated to its inertia properties. Because of this, a separate operation is needed to add mass and inertia to the nacelle. **The user should finish creating the hub before coming back to it for a separate MODIFY operation to add inertia properties.**

The DELETE panel for the hub is self-explanatory.

The RELOCATE panel is used to move the hub to the end of the shaft and attach it there. If the standard low-speed shaft is used, WT will create the appropriate revolute (for teetering hubs) or fixed (for rigid hubs) JOINT to attach it to the *hub_mount* marker. The RELOCATE panel is shown below:



Base Marker on Hub

The ADAMS/View name of MARKER on the hub for which you want to specify a new position. After the relocation, the base marker will overlay the target marker exactly. Normally, the *hub_center* MARKER on the hub is relocated onto the *hub_mount* MARKER on the low-speed shaft.

Target Location Marker

The ADAMS/View name of any MARKER on any other PART in the model. After the relocation, the base marker on the nacelle will have the exact same position and orientation as the target marker.

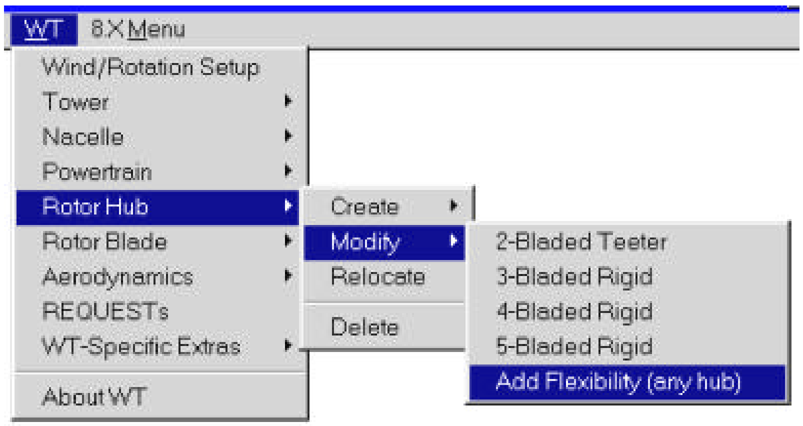
Type of Attachment to Shaft

This field can be cycled using the cycle button to choose between "none" (no attachment, just relocate), "rigid" (relocate and connect with fixed joint) and "teeter" (relocate and connect with revolute joint). The rigid option will work with any type of hub and will create a fixed-type JOINT between the target and base

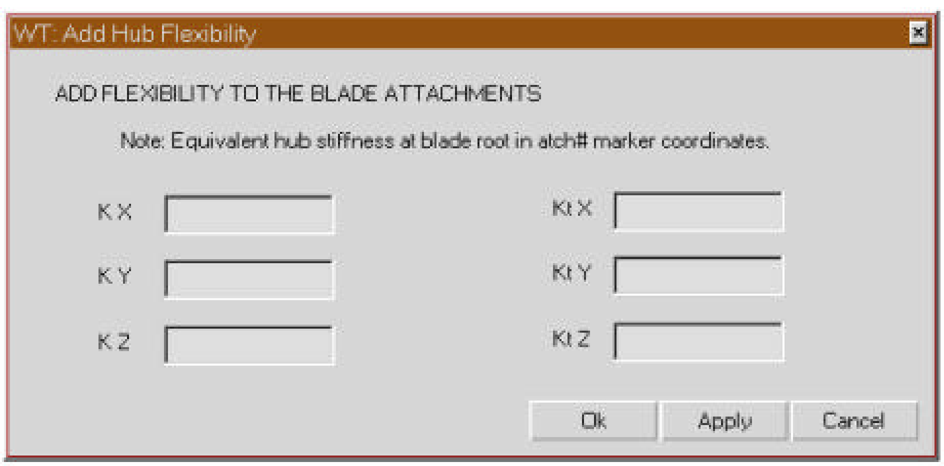
MARKERs named *hub2shaft*. The teeter option will only work for standard, WT-created teetering hubs, when there is an existing *teeter* marker on the *hub* PART. WT will automatically create a MARKER named *hinge* on the *lss2* PART to complete the joint.

5.5.5 Hub Flexibility

If you wish to consider the some hub flexibility in your model, you can use the ADD FLEXIBILITY button under the HUB MODIFY menu:



This brings up the following panel:



k_x

The effective translational stiffness of the hub, *at the blade attachment markers,* along the x-axes of those markers, N/m.

k_y

The effective translational stiffness of the hub, *at the blade attachment markers,* along the y-axes of those markers, N/m.

k_z

The effective translational stiffness of the hub, *at the blade attachment markers,* along the z-axis of those markers, N/m.

kt_x

The effective rotational stiffness of the hub, *at the blade attachment markers*, about the x-axis of those markers, N-m/rad.

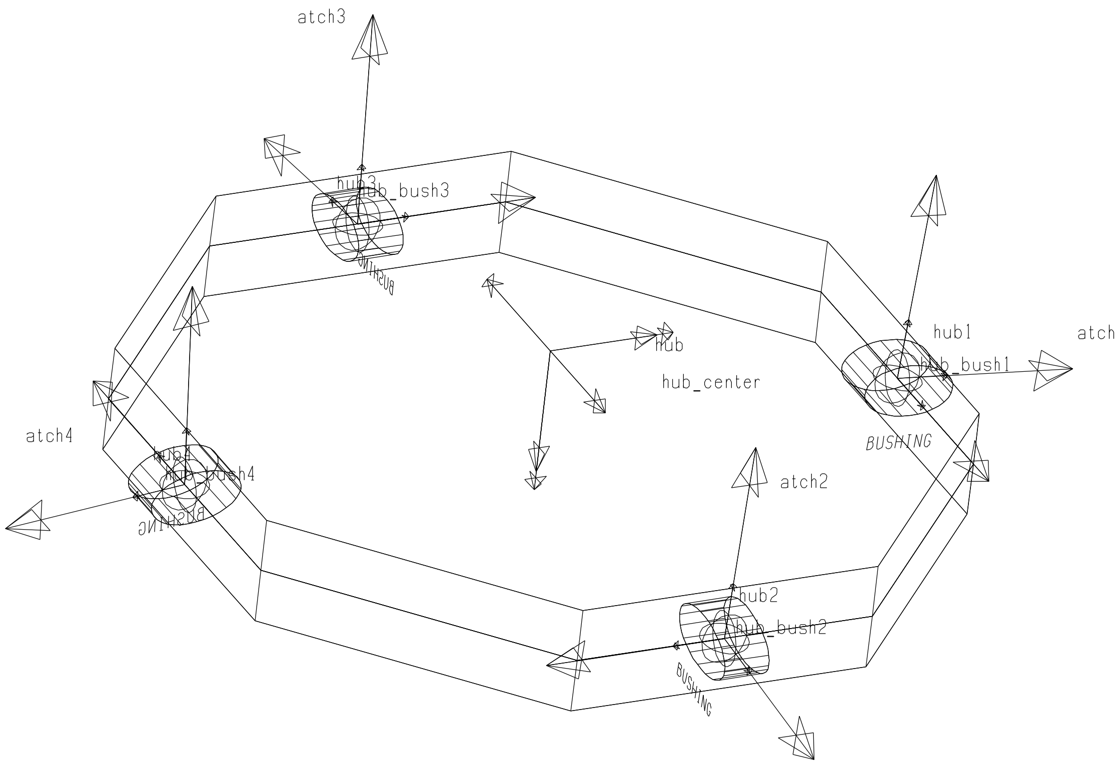
kt_y

The effective rotational stiffness of the hub, *at the blade attachment markers,* about the y-axis of those markers, N-m/rad.

kt_z

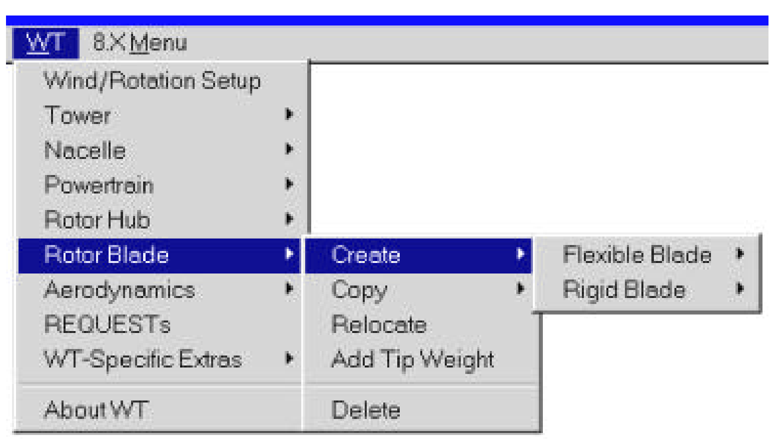
The effective rotational stiffness of the hub, *at the blade attachment markers*, about the z-axis of those markers, N-m/rad.

Executing this panel (by selecting OK or APPLY) will add flexible BUSHING elements between the dummy PARTs at the blade attachment markers and the hub itself. This ADAMS element can be thought of as a combination of six springdampers at a single point, one for each direction. ADAMS/WT will automatically add damping in each direction equal to 1% of the appropriate stiffness value. A four-bladed hub with added flexibility is shown below:



5.6 Rotor Blades

While not containing so many different kinds of substructures as the power train, the rotor blade aggregate elements contain the most innovative and elaborate macro coding in ADAMS/WT. The rotor blades, both flexible and rigid/hinged, use many of the new macro constructs, database access and expression functions that became available in the 8.0 version of ADAMS/View. The blade aggregate elements are accessed through the main ADAMS/WT menu:



As can be seen in the menus, the two blade types share common menu picks (although not completely common macro code) for the RELOCATE, COPY and DELETE operations. The creation operations for the flexible and rigid/hinged blade types differ significantly, despite the similarity of their data entry panels and the fact that they both use the same data file (see below and Appendix G). Note that most of the detailed graphics in this section are reproduced from the 1.50 version of WT, since they are easier to see without color

5.6.1 Blade Properties

Regardless of whether you plan to use flexible or rigid blades, you will need to put the blades' inertial and structural properties into a file that WT can read during blade creation. As mentioned, the format for this ASCII file can be found in Appendix G. Some discussion of the various quantities in the file is needed, however, before getting into the details of exactly how to create a blade.

Note that the data in this file, given as a function of radial location, are not used *directly* to define the rotor blade. Instead, these data are interpolated at the correct radial stations to give the necessary inputs for each individual tapered part and tapered beam in the blade. For this reason, ***all data are given per unit length where appropriate.*** The main blade creation macros call the tapered PART and tapered-beam FIELD macros multiple times to create a full blade.

For each radial station where you want to give data, the file will contain four lines. Typically, all blades are defined from the same data file, but this is not required. WT will automatically create a reference MARKER for each blade called *bl#_refmark* which is used as the reference coordinate system for defining the blade. You need to be very careful about how you relocate the blades to the hub to ensure that the structural twist and aerodynamic twist are correctly oriented with respect to the rotation. This is especially true for rigid blades, which are not *structurally* twisted but can be aerodynamically twisted.

The first line in each radial group contains:

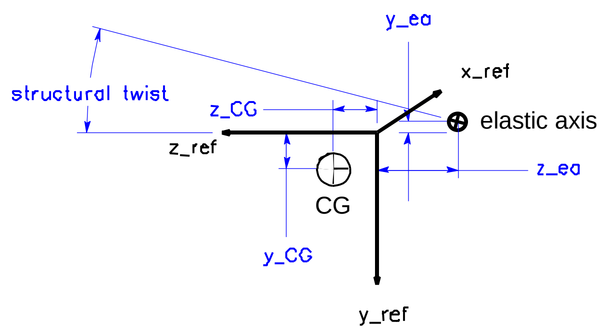
1. radial station for this data group, measured from center of rotation, given in meters
2. mass/length at this station, given in kg/meter
3. second mass moment of inertia about the y-axis, given in kg-m^2/meter
4. second mass moment of inertia about the z-axis, given in kg-m^2/meter

The second line in the group contains:

1. thickness-wise (y) offset of the section CG from the blade reference x-axis, in the blade reference coordinates, given in meters
2. chord-wise (z) offset of the section CG from the blade reference x-axis, in the blade reference coordinates, given in meters
3. thickness-wise (y) offset of the local elastic axis from the blade reference x-axis, in the blade reference coordinates, given in meters. The local elastic axis, also sometimes referred to as the center-of-twist, is the point about which, if you apply a torque, you would get pure rotation response.

4. chord-wise (z) offset of the local elastic axis from the blade reference x-axis, in the blade reference coordinates, given in meters
5. structural twist at this radial station, defined about the blade reference x-axis, given in degrees

These quantities are shown schematically in the figure below. Note that structural twist and aerodynamic twist do not have to be the same.



The third line in the radial data group contains structural information:

1. section torsional stiffness (GJ) about elastic axis, given in Newton-meter^2
2. section extensional stiffness (EA), given in Newton
3. section bending stiffness (EI_y) about twisted elastic y-axis, given in Newton-meter^2
4. section bending stiffness (EI_z) about twisted elastic z-axis, given in Newton-meter^2

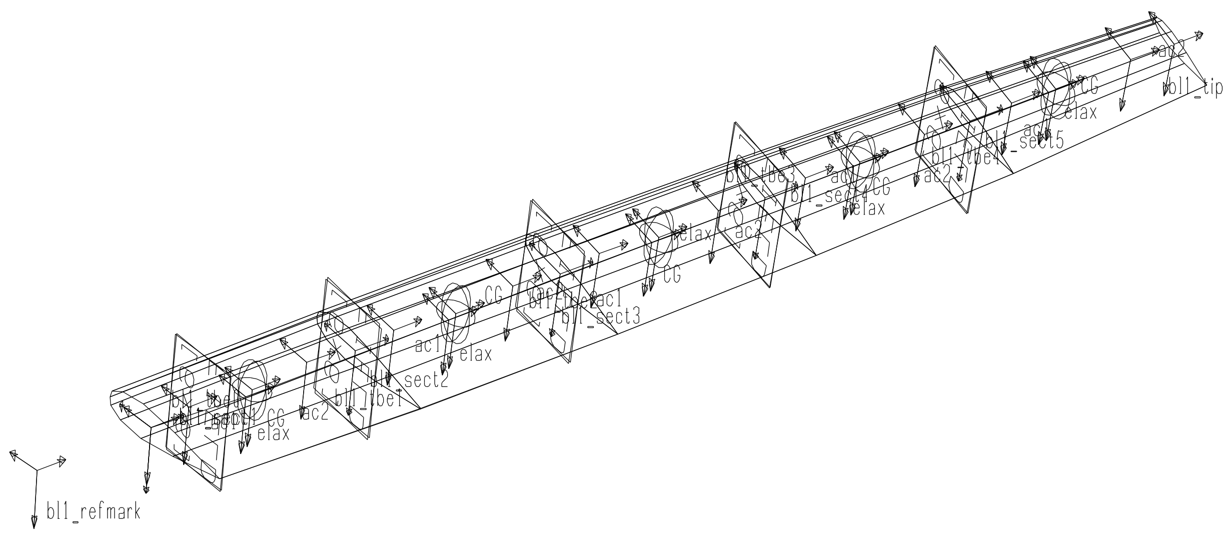
The fourth and last line in each group contains aerodynamic data. Note that the aerodynamic data and the structural data are independent, i.e. the twist values and offsets are measured completely separately (both are relative to the same blade reference axes, however).

1. chord length at this radius, given in meters
2. *chordwise* offset of the section aerodynamic center from the reference x-axis, with positive toward the leading edge (+z), given in meters
3. *aerodynamic* twist at this station, measured about the reference x-axis, measured in degrees

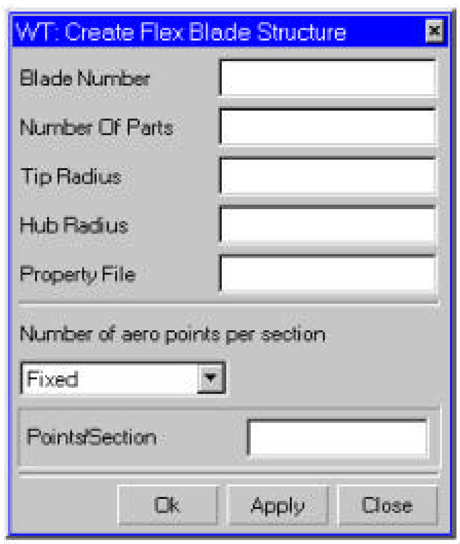
5.6.2 Flexible Rotor Blade

As mentioned above, the tower aggregate element is very similar to the flexible blade aggregate element. Both are modeled as engineering thin beams, but the flexible blade aggregate element additionally allows for both structural and aerodynamic twist, not necessarily coincident. Both the aerodynamic and structural twist are defined with respect to a reference marker called *bl#_refmark*, where the # is replaced by the blade number. Twist is defined positive about the +x axis of the reference marker, which for the default rotor configuration gives positive twist out of the wind.

The flexible blade element can also accommodate an elastic axis which is not *strictly* parallel to the reference axis for the length of the blade. Small offsets (up to 5% of chord length) from the reference axis in both chordwise and thickness-wise directions are possible. Finally, in place of the tower's simple frustum graphics, airfoil-shaped envelope graphics are automatically generated for the blade, based on a 0012 section profile, but following the aerodynamic twist and taper.



The data entry panel for the flexible blade structure is shown below:



Like the tower aggregate element, the entry panel for the flexible blade is deceptively simple because the blade structural and aerodynamic properties data, such as the stiffness, chord, etc., are contained in an external file. Also like the tower, ADAMS/WT interpolates and smoothes these data in an external utility program (*wtblade.exe).* This program produces the section end point values which are used in creation of the appropriate tapered beam FIELD, tapered PART and graphics elements. These data are also used to correctly place and orient the aerodynamic center MARKERs.

Blade Number

The blades are distinguished by numbering, which should be consecutive from 1. The PARTs and FIELDs associated with blade # will all have ADAMS/View names which begin with "*bl#_*". This naming/numbering scheme is used later for copying, relocating and/or deleting a complete blade structure.

Number of blade parts

The number of equal-<u>length</u> tapered PARTs to put in the blade. Numerical experimentation has shown that equal-length sections of the blade give both good response and good convergence results. ADAMS/WT will generate equal-length tapered beams between the PART CG's and an extra half-length beam between the most inboard section CG and the root end. For the flexible blade, PARTs and aerodynamic sections correspond exactly.

Tip Radius

The distance from the axis of rotation to the blade tip, that is the outermost part of the blade for which the aerodynamic formulation will be applied. Measured parallel to the blade reference axis, m.

Hub Radius

The distance from the axis of rotation to the blade root, that is the outermost part of the blade for which the aerodynamic formulation will be applied, m. Measured parallel to the blade reference axis.

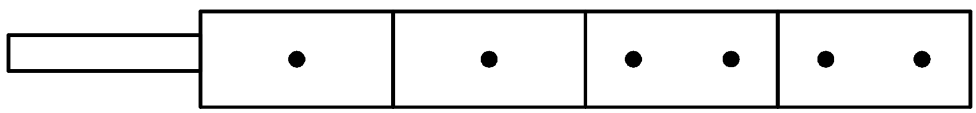
File of blade properties

The actual inertial, stiffness and aerodynamic properties for the blade must be in this external file. *The need for accurate blade properties for analysis input can not be overemphasized*. This file lists, as a function of radius, the mass/unit length, section mass moments of inertia, section CG offsets from the reference axis, structural twist, torsional stiffness, lateral stiffnesses, extensional stiffness, chord length, chordwise offset of the aerodynamic center from the reference axis and aerodynamic twist.

ADAMS/WT interpolates and smoothes this data using the external program *wtblade.exe* to get the end point values passed in to the macros that build the tapered beam FIELD and tapered PART elements and place the aerodynamic center markers at the appropriate Gaussian integration points for each PART as determined below. A detailed description of the data file format and contents is given in Appendix G.

Number of Aero_Points per Section
Fixed / List by Section

These two options can be alternated using the cycle button on the panel. When the title reads "Fixed," you enter either 0, 1 or 2 and WT will put that many aerodynamic center markers on each blade part, at the Gaussian integration points. When the title reads "List by Section," you can separately specify 0, 1 or 2 points for each blade part, going from the root outwards. For example, say that you wanted to distribute your control points as shown below:

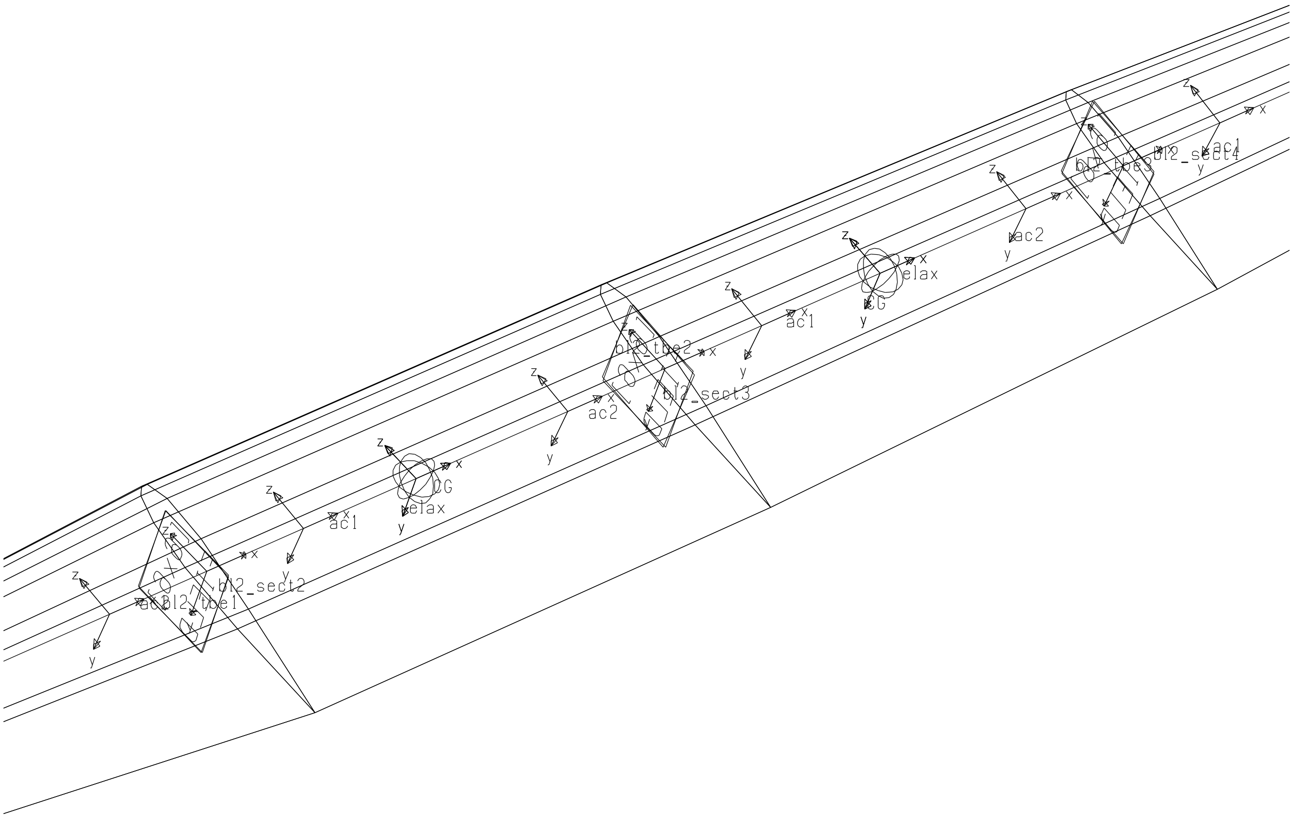


To do this, you would enter *0,1,1,2,2* in the field.

When all the data are entered and the panel is executed, ADAMS/WT will begin the process of creating the flexible blade structure. First, WT will run the *wtblade.exe* utility program, which creates a set of intermediate temporary files containing the interpolated property data for each blade section. These files are automatically read back into View, whereupon the macros to finally build the blade itself are executed. The blade will be built in the order of PARTs, FIELDs, MARKERs and finally the surface graphics. This can take several minutes, depending on how many sections are in the blade and the speed of your platform.

Like the tower, each pair of parts in the flexible is connected by one of the special WT tapered beam FIELD elements, running between the elastic axis MARKERs. When the blade is created, the inboard-most part is connected to a dummy marker on *ground* called *temp_atch#* using a half-length tapered beam element called *bl#_tbe0*. (The # represents the blade number.) This is shown in the following figure.

The blade parts are named *bl#_sect#*, numbered from hub outward starting with 1. The special tapered beam FIELD elements are named *bl#_tbe#*, again numbered from the hub outward, starting with 0. Each of these is arranged with the J marker for the FIELD on the inboard side and the I marker on the outboard. For example, for *bl2_tbe2*, the J marker is *bl2_sect2.elax* and the I marker is *bl2_sect3.elax*. If the blade is structurally twisted, the elastic axis MARKERs will be oriented to follow that twist.



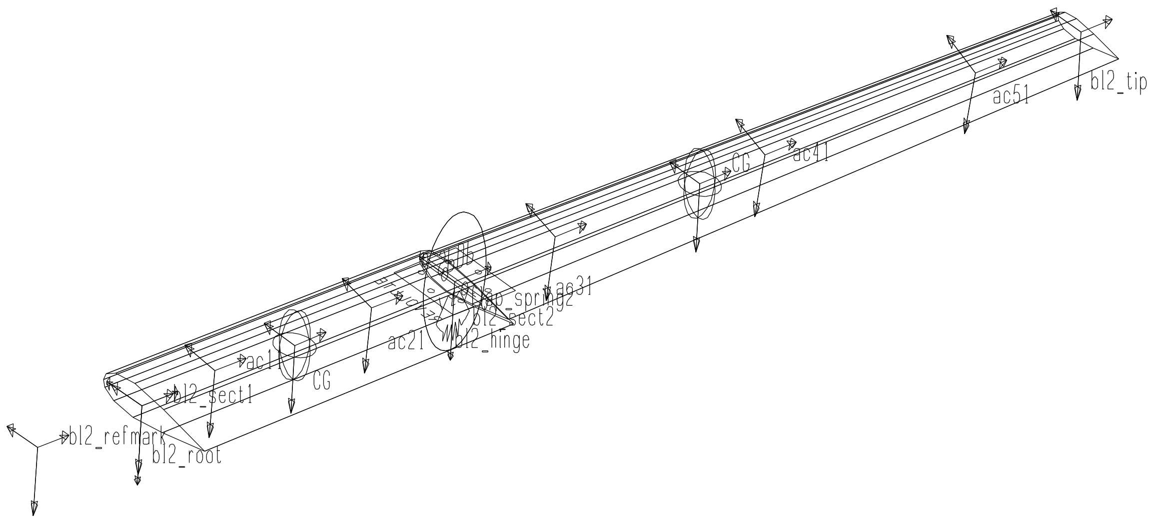
Note that the blade graphics in ADAMS/WT are based on a simple, symmetrical section profile which is copied, scaled and rotated appropriately at each section end point. The corresponding vertices of each section are then connected along the length of the blade. Although the graphical depiction of the blade envelope is completely unrelated to the aerodynamic performance, the user may desire to substitute a more realistic-looking profile for his model. The profile data can be changed. It is coded in the macro file *blsu.mac* in the *comfiles* subdirectory, which contains the macro *wt_bla_sur*. Note that the normalized chord length of the profile is 4 and that it is defined with respect to the blade reference axis, not the ¼-chord.

5.6.3 Rigid/Hinged Blade

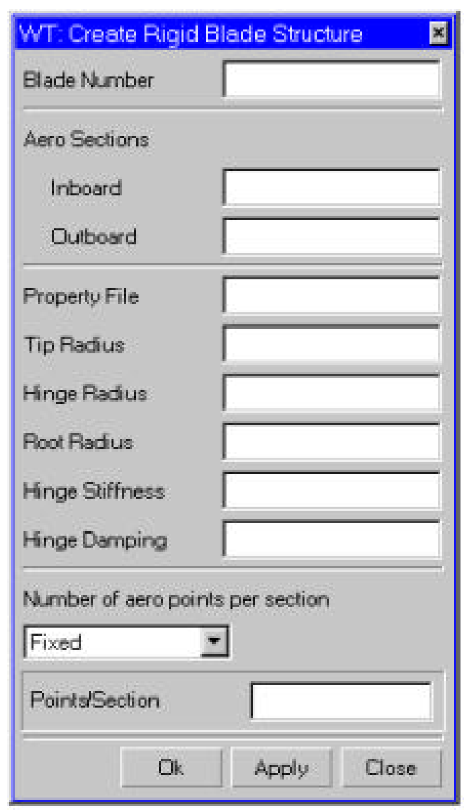
The rigid/hinged blade aggregate element in ADAMS/WT produces the classical straight, rigid blade plus flapping hinge approximation often used for initial rotor dynamics investigations. For teetering rotors, ADAMS/WT uses this option for completely rigid blades, too.

The rigid/hinged blade uses the same input file format as the flexible blade (Appendix H), but ignores the stiffness information. The blade is generated as two tapered PARTs, one on either side of the hinge. ADAMS/WT integrates the inertia properties to get the right values for each blade piece.

Instead of the number of blade PARTs, the user must specify the number of aerodynamic sections to be put on each side of the hinge, and the number of aerodynamics control points to put in each section. The aerodynamic center markers will follow the aerodynamic twist given in the input file. The hinge, however, will <u>not</u> be set at the structural twist angle corresponding to its radial location. *This means that the blade will flap parallel to the z-axis of the attachment marker*, <u>not</u> strictly out of the plane of rotation. This can produce some coupling effect (not strictly "flap-only").



The data entry panel for the rigid/hinged blade is shown here:



Blade Number

The blades are distinguished by numbering, which should be consecutive from 1. The PARTs associated with blade # will all have ADAMS/View names which begin with "*bl#_*". This naming/numbering scheme is used later for copying, relocating and/or deleting a complete blade structure.

Aero Sections Inboard

The number of equal-length aerodynamic sections to be put on the section of the blade inboard of the hinge. ADAMS/WT will place two aerodynamic center markers on each section at the spanwise Gaussian integration points.

Aero Sections Outboard

The number of equal-length aerodynamic sections to be put on the section of the blade outboard of the hinge. ADAMS/WT will place two aerodynamic center markers on each section at the spanwise Gaussian integration points.

Property File

The actual inertial, stiffness and aerodynamic properties for the blade must be in this external file. *The need for accurate blade properties for analysis input can not be overemphasized.* This file lists, as a function of radius, the mass/unit length, section mass moments of inertia, section CG offsets from the reference axis, structural twist, torsional stiffness, lateral stiffnesses, extensional stiffness, chord length, chordwise offset of the aerodynamic center from the reference axis and aerodynamic twist. ADAMS/WT interpolates and smoothes this data using the external program *wtrigid.exe* to get the end point values for the tapered PART element macros, and to place and orient the aerodynamic center markers for each aerodynamic section. A detailed description of the data file format and contents is given in Appendix I.

Tip Radius

The distance from the axis of rotation to the blade tip, that is the outermost part of the blade for which the aerodynamic formulation will be applied, m. Measured parallel to the blade reference axis.

Hub Radius

The distance from the axis of rotation to the blade root, that is the outermost part of the blade for which the aerodynamic formulation will be applied, m. Measured parallel to the blade reference axis.

Hinge Radius

The distance from the axis of rotation to the blade hinge, measured parallel to the blade reference axis, m.

Hinge Stiffness

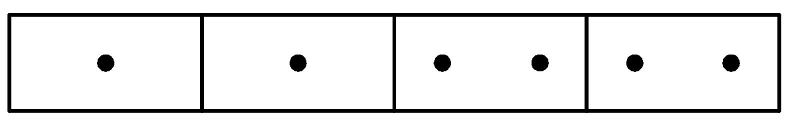
The stiffness of the torsional SPRINGDAMPER on the flapping hinge revolute JOINT, N-m/deg. This spring is normally used to get the blade to match the real blades first mode frequency. If the user enters zero values for both stiffness and damping, ADAMS/WT will create only one PART and consider it as the outboard piece for naming/numbering purposes. This produces a truly "rigid" blade.

Hinge Damping

The damping coefficient of the torsional SPRINGDAMPER on the flapping hinge revolute JOINT, N-m-sec/deg. This damper is normally used to get the blade to match the real blades first mode damping. If the user enters zero values for both stiffness and damping, ADAMS/WT will create only one PART and consider it as the outboard piece for naming/numbering purposes.

Number of Aero_Points per Section
Fixed / List by Section

These two options can be alternated using the cycle button on the panel. When the title reads "Fixed," you enter either 0, 1 or 2 and WT will put that many aerodynamic center markers on each blade part, at the Gaussian integration points. When the title reads "List by Section," you can separately specify 0, 1 or 2 points for each blade part, going from the root outwards. For example, say that you had specified 2 inboard and 2 outboard sections and wanted to distribute your control points as shown below:



To do this, you would enter *1,1,2,2* in this field.

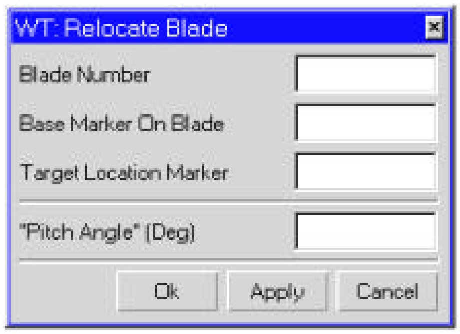
The DELETE panel for rotor blades is self-explanatory, merely asking which number blade the user wishes to delete. When the blade is deleted, all associated ADAMS elements are deleted with it, including aerodynamic forces, tip weights, etc.

There is no MODIFY panel for the blade. Since most of the blade information is actually in the external file and blade creation is so easy, ADAMS/WT requires you to delete the entire blade aggregate element and create a new one, instead of modifying the existing one.

The COPY panel is also self-explanatory, asking only which blade number to copy and what number to name the new one. The blade copy function should only be used with great caution, however, since it uses ADAMS/View's internal copying commands and the new blade will not follow the same ADAMS ID numbering for its component pieces. Especially when using the AeroDyn subroutines for airloads, the preferred method for creating multiple blades is to create each blade individually, not to create one and copy it. This ensures that the PART and MARKER numbering will be consistent for all blades.

5.6.4 Blade Relocation

The rotor blade RELOCATE panel (also available as the CREATE xxx ROOT_SETUP panel) is shown below. This panel works correctly regardless of the direction of rotor rotation, because both the *bl#_root* and *atch#* MARKERs are oriented corresponding to the direction of rotation, pointing outward for clockwise rotation and inward for counter-clockwise rotation.



Blade Number

Which blade you want to relocate.

Base Marker on Blade

The ADAMS/View name of MARKER on the blade for which you want to specify a new position. After the relocation, the base marker will overlay the target marker exactly. Normally, the *bl#_root* MARKER on the blade is relocated onto the *atch#* MARKER on the hub, where # is the blade number.

Target Location Marker

The ADAMS/View name of any MARKER on any other PART in the model. After the relocation, the base marker on the blade will have the exact same position and orientation as the target marker. Since rotor blades are built "on the ground", ADAMS/WT expects to have to relocate them to the attachment points on the hub. For flexible blades, ADAMS/WT will move the blade, disconnect the inboard end of the first tapered beam element from its temporary place holder and then connect it to the target marker. For rigid blades, WT will attach the base marker to the target marker with a fixed-type JOINT.

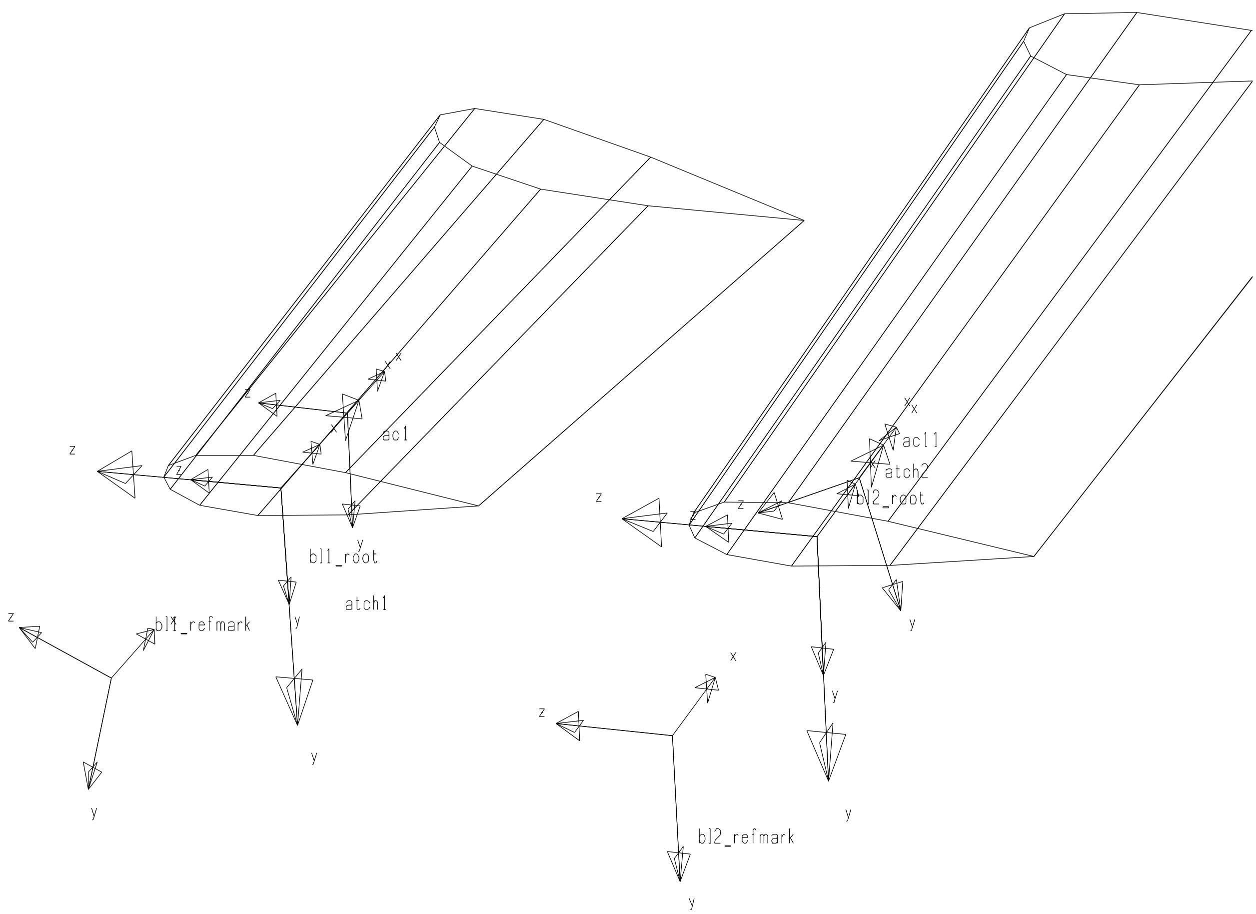
Pitch Angle

The angle in degrees from the z-axis of the target location MARKER to the z-axis of the base MARKER, defined with the positive sense about the x-axis of the target MARKER.

5.6.5 Blade Pitch Definition

It is useful here to look at the differences between how blade construction and relocation works for rigid and flexible blades. For the purposes of clarity in this example we are going to assume that the blade is has a very large, linearly-distributed, structural and aerodynamic twist running from -20° at the blade root to +20° at the blade tip. We will then consider how each blade might be mounted to get the same effective aerodynamic performance. The arguments below work equivalently for both clockwise and counter-clockwise rotating rotors. A clockwise-rotating rotor is used as the example because they are more common. First, let's look at what happens to each type of blade if you mount the blade root marker (*bl#_root*) to the attachment marker with zero pitch angle.

Flexible Blade　　　　Rigid Blade

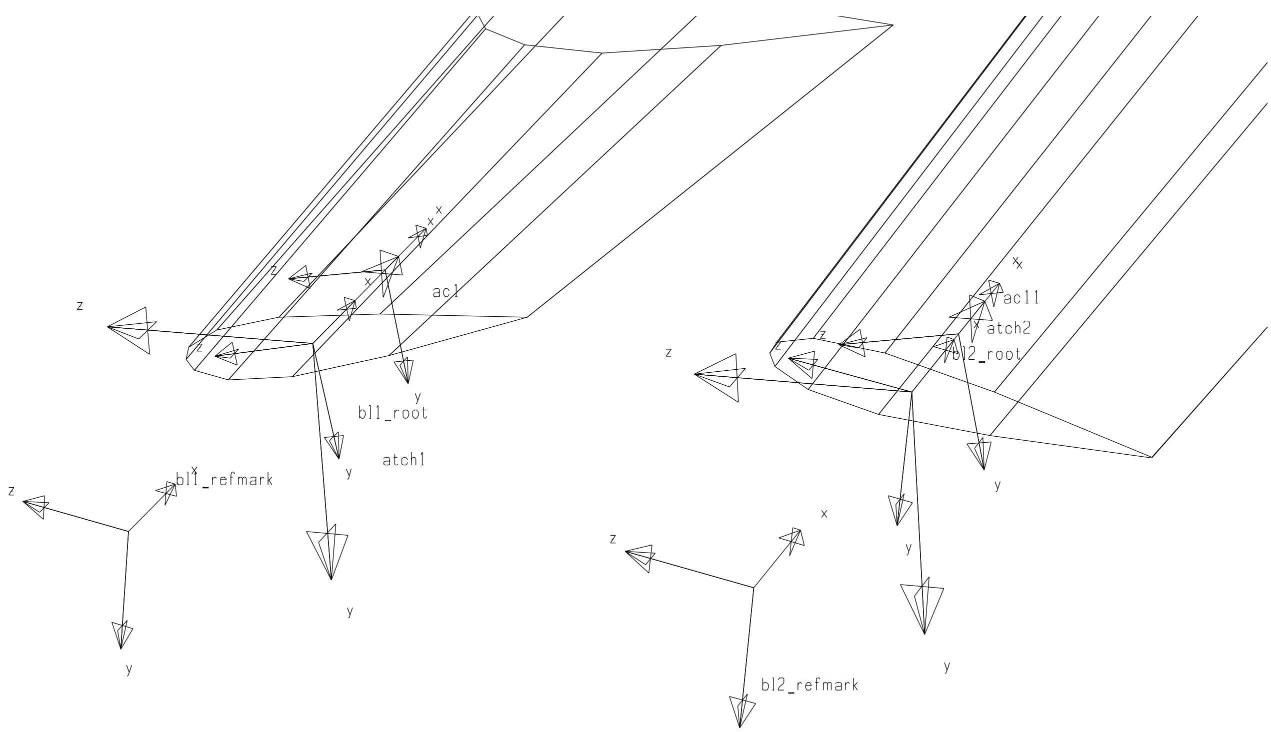


Because the flexible blade is both structurally and aerodynamically twisted, the blade root marker, *bl1_root*, is set at -20° with respect to the reference marker, *bl1_refmark*. Therefore when you relocate the root to the attachment marker, you can see that the reference axes appear to be rotated up 20°, while the first aerodynamic control marker is nearly lined up with the blade root.

The rigid blade, on the other hand, is not structurally twisted at all. It has only aerodynamic twist. This means that the *bl2_root* marker is aligned with the *bl2_refmark* marker instead of being offset by the root twist angle. When you relocate the root to the attachment marker, you can see that the reference axes now line up with the attachment marker, while the first aerodynamic control marker is set about at the -20° root pitch angle. Note that in this case, because we set a 0° pitch angle, the flapping hinge axis will be exactly in the plane of rotation. It also is aligned with the blade root marker and blade reference marker.

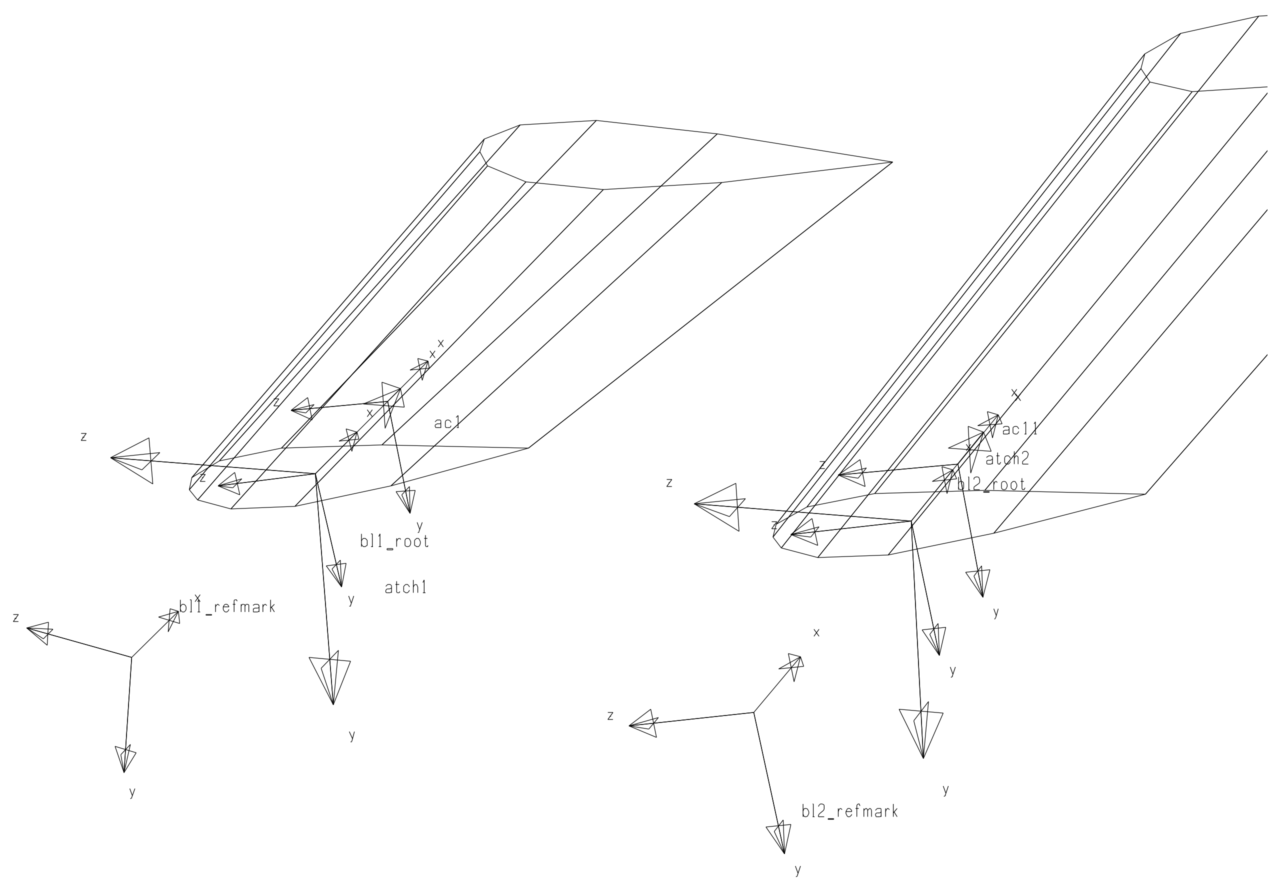
So to get the "correct" aerodynamics from these blades, you could set the flexible blade at a pitch angle equal to the actual angle of the blade root when installed, and the rigid blade at an angle equal to the actual angle minus the root aerodynamic twist angle. For example, if this same blade were install in the hub with a measured angle between the blade root and plane of rotation of -10°, the flexible blade should be relocated with a -10° pitch angle and the rigid blade should be installed with a +10° (-10 - -20) pitch angle.

In the figure below, you should note that the orientations of the first aerodynamic control markers (*ac1* and *ac11*) are very close, as are the reference markers (*bl1_refmark* and *bl2_refmark*). Not shown here is the rigid blade's hinge, which is also now pitched at a +10° angle also and probably would give some unwanted coupling effects. Of course, the hinge can be reoriented to avoid this.



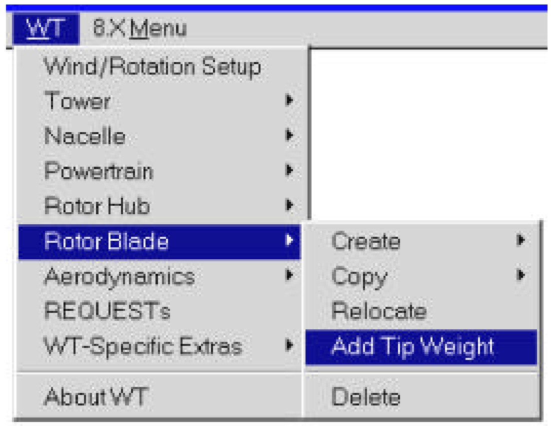
Clearly, this is not an optimal modeling approach, since the blade envelope graphics are not consistent with the aerodynamics. (This has no effect on the response, of course.) Something standardized method for attaching the blade to the hub is necessary, however, because of the many and various definitions in use in industry for the quantities "blade pitch" and for "blade twist." By working with this definition of twist and pitch in ADAMS/WT, the careful user should be able to correctly build and install any real rotor blade by deliberately and systematically combining the twist in the rotor data file and the pitch angle in the relocation panel.

For example, if the aerodynamic twist angles in a rigid blade data file are shifted up by minus the corresponding twist structural angles, the two types of blades can be set at the same pitch angle and everything will "look" OK. (Except for the hinge and reference markers, and you now have to maintain two separate data files.) This is shown in the following figure. Another approach might be to manually add a different attachment MARKER on the blade, or to adjust the orientation of the blade root marker, before relocating it to the hub. Some combination of these approaches could also allow the flapping hinge remain aligned with the plane of rotation to retain a "flap-only" response if desired, or to aligned it exactly as needed. Users who will often be switching back and forth between rigid and flexible blades should decide on a single approach and stick to it. MDI will be happy to work with individual users to create the necessary WT code modifications for any chosen "standard".



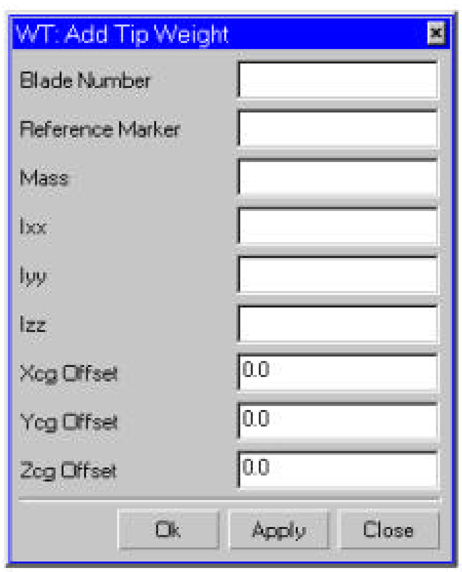
5.6.6 Adding Tip Weights

ADAMS/WT allows you to add fixed tip weights to any blade using the ADD TIP WEIGHT selection on the ROTOR BLADE sub-menu:



For simplicity, only the principal-axis inertia properties of the tip weight can be defined, although the center of gravity can be offset from the attachment marker. If the weight is strangely shaped or oriented, you may want to adjust its position and inertia properties manually after creating it, using the PART MODIFY RIGID-BODY MASS_PROPERTIES functionality from the command navigator.

Selecting ADD TIP WEIGHT displays the following panel:



Blade Number

The integer number of the blade to which the tip weight will be added. The tip weight PART will automatically be called *bl#_tipwt*, where # is the blade number.

Reference Marker

The name of the MARKER to which the tip weight will be attached, typically this will be *bl#_tip*, where # is the blade number. This is also used as the coordinate system to define the mass offsets.

Mass

The mass of the tip weight, kg.

Ixx

The second <u>mass</u> moment of inertia of the tip weight about the x axis of the center of gravity, kg-m^2.

Iyy

The second <u>mass</u> moment of inertia of the tip weight about the y axis of the center of gravity, kg-m^2.

Izz

The second <u>mass</u> moment of inertia of the tip weight about the z axis of the center of gravity, kg-m^2.

Xcg_offset

The offset of the tip weight center of gravity from the reference MARKER given above, along that MARKER's x axis, meters. If *bl#_tip* is used, the x direction is radially outward along the blade axis.

Ycg_offset

The offset of the tip weight center of gravity from the reference MARKER given above, along that MARKER's y axis, meters. If *bl#_tip* is used, the y direction is nominally into the wind with respect to the blade.

Zcg_offset

The offset of the tip weight center of gravity from the reference MARKER given above, along that MARKER's z axis, meters. If *bl#_tip* is used, the z direction is toward the leading edge.

After executing this panel by selecting OK or APPLY, ADAMS/WT will create the *bl#_tipwt* PART, attach it to the reference marker using a FIXED-type JOINT named *bl#_tipweld*, and add a representative thin disk graphic for visualization purposes. Note that the mass properties of the tip weight are defined by the panel, not by the graphic.

A blade tip with added tip weight is shown below: